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UPWASH ANGLES NEAR ENGINE INLETS OF AN EXTERNALLY BLOWN FLAP STOL TRANSPORT

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16. Abstract

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Large upflow angles exist near the inlets of the nacelles; the highest value (67.3°) occurred with flaps at $15^\circ, 35^\circ, 55^\circ$, an angle of attack of 25.7°, and a thrust coefficient of 4. The upflow angle was found to be strongly dependent on the circulation lift, regardless of the flap deflection, angle of attack, or thrust coefficient used to generate this circulation lift. The potential-flow calculations away from the nacelle inlets agreed fairly well with the experimental data.

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SUMMARY

An investigation has been conducted in the Langley V/STOL tunnel to determine the upwash flow angles in the region of the nacelle inlets of a representative powered-lift transport configuration operating at high lift coefficients. The upwash angles were indicated by tufts and measured from photographs. A potential-flow program was used to estimate these flow angles.

Large upflow angles exist near the inlets of the nacelles; the highest value (67.3^O) occurred with flaps at $15^O, 35^O, 55^O$, an angle of attack of 25.7^O, and a thrust coefficient of 4. The upflow angle was found to be strongly dependent on the circulation lift, regardless of the flap deflection, angle of attack, or thrust coefficient used to generate this circulation lift. The potential-flow calculations away from the nacelle inlets agreed fairly well with the experimental data.

INTRODUCTION

An aircraft capable of efficient cruise performance and also short take-off and landing (STOL) would generally have a powered high-lift system. This lift system, in developing lift coefficients approaching 10, induces large upwash angles in front of the wing in the region of the nacelles. These flow fields must be defined in order that the nacelles can be properly designed to minimize flow distortion at the engine face.

Some theoretical work has been done to calculate the flow field using two-dimensional potential flow (ref. 1) and two-dimensional flow modified to include three-dimensional effects (ref. 2). Little experimental work has been made available for design and comparison with calculated values of the flow field associated with the high lift coefficient generated by STOL aircraft. Maximum upwash angles for conventional take-off and landing (CTOL) transport aircraft are near 10° (ref. 3). STOL aircraft producing very high lift coefficients

generate upwash angles of the order of 50°; therefore, the engine-inlet flow distortion is much more severe for a STOL aircraft.

In the present investigation flow angles were measured at two spanwise stations in the vicinity of the nacelles of a four-engine externally blown flap STOL transport model by reading photographs of a tuft grid placed streamwise and adjacent to the engine nacelles. Theoretical estimates of the upwash angle were made by computing the wing circulation distribution with the vortex-lattice method of reference 4 and then evaluating the flow field from a modified version of this vortex-lattice method.

Diagrams of the flow fields determined from the test photographs for landing and take-off flap deflections are presented. Test conditions included a range of thrust coefficient from 0 to 4.0 and a range of lift coefficient from 1.9 to 9.3. Estimated values of up-flow angles are compared to the experimentally determined values.

SYMBOLS

The values in this paper are given in both SI and U.S. Customary Units. Measurements and calculations were made in U.S. Customary Units. Factors relating these units are given in reference 5.

b	wing span, 1.90 m (6.25 ft)
C_L	tail-off lift coefficient, $\dfrac{\text{Lift}}{qS}$
$C_{L,\Gamma}$	thrust-removed (circulation) lift coefficient, $C_L - \eta C_\mu \sin\left(\alpha + \delta_j\right)$
C_μ	thrust coefficient, $\dfrac{\text{Static thrust}}{qS}$
$\bar{c}$	mean geometric chord, m (ft)
F_A	axial force, N (lb)
F_N	normal force, N (lb)
q	free-stream dynamic pressure, Pa (lb/ft^2)
R	radius of upper half of nacelle, $0.065\dfrac{b}{2}$
S	wing area, m^2 (ft^2)

2

| V | free-stream velocity, m/sec (ft/sec) |

| V | free-stream velocity, m/sec (ft/sec) |

X,Y   axes used for wing planform definition

x,y   coordinates of breakpoints of wing planform, x positive forward and y positive toward right wing, cm (in.)

x/c   fraction of projected wing chord (slats and flaps included)

$\dfrac{y}{b/2}$ tuft grid location, fraction of semispan

z   vertical location of grid relative to wing-chord plane, m (ft)

α angle of attack, deg

δ_f flap deflection, positive trailing edge down, deg

δ_j jet-exhaust deflection angle, $\arctan \dfrac{F_N}{F_A}$, deg

η flap turning efficiency, $\dfrac{\sqrt{F_N{}^2 + F_A{}^2}}{\text{Thrust}}$

θ local upflow angle, measured with respect to model horizontal axis, deg

ϕ local upwash angle, measured with respect to free stream, deg

MODEL AND APPARATUS

The model was a typical powered-lift configuration equipped with externally blown, triple-slotted flaps. Geometric characteristics of the model are given in figure 1. Photographs of the model installed in the Langley V/STOL tunnel with tail on are presented in figure 2. The model had full-span flaps which were deflected to represent the take-off and landing configurations (fig. 3). The series of numbers which designate the trailing-edge flap deflections are for the three elements of the flap system.

A large chord slat, set at a deflection of 50°, was used in conjunction with the flaps. For some tests, wood fillers were installed to close the gap between the slat and the nacelles. One of the fillers can be seen in figure 2 at the inboard end of the outboard slat.

The four nacelles installed on the model were located below and forward of the wing. The exhaust flow of the high-bypass-ratio engines were simulated by two-part ejectors using compressed air. The details of these ejectors are presented in reference 6. Further geometric characteristics of this model can be found in reference 7.

The frame for the tuft grid used to indicate the flow angles ahead of the wing was constructed of steel rods and bolted to the outboard sides of the port nacelles. The grid was constructed in units of R, which is the radius of the upper half of the nacelle (fig. 4). Wire standoff masts were used to decrease the interference of the supporting frame. In addition, four long tufts were installed on masts long enough to put the tufts on the vertical plane of the center line of the nacelle inlet and were used only during the landing configuration tests. The tuft locations are presented in figure 4.

TEST AND PROCEDURES

This investigation was conducted in the Langley V/STOL tunnel at a nominal free-stream dynamic pressure of 479 Pa (10 lb/ft^2) for a Reynolds number of 0.54×10^6, based on the wing mean geometric chord of 27.81 cm (10.95 in.). For this investigation the horizontal tail was off. Most of the tests were made over an angle-of-attack range of 0° to 25° for static thrust coefficients of 0, 2, and 4. The various thrust levels were obtained by setting the primary air-supply pressure at the model plenum in accordance with a previously determined relationship between model plenum pressure and model thrust.

Force and flow-angle measurements were made at selected angles of attack and thrust coefficients. A complete investigation had already been conducted to determine the longitudinal aerodynamics of this model (ref. 7). Maximum angle-of-attack corrections due to wind-tunnel wall effects were determined to be approximately 0.5^O in reference 7; therefore, no corrections to these data have been made.

Flow-angle data were recorded by a camera for the landing and take-off configurations at $C_\mu = 0, 2,$ and 4 and three angles of attack (near zero, midway to stall, and just below stall). Test conditions and configurations are listed in table I. The angle of each tuft was measured relative to the body axis on the photograph. An example of the photographs taken is presented in figure 5.

PRESENTATION OF RESULTS

The tail-off lift-coefficient characteristics of the model which pertain to this investigation are presented in figure 6. These data were obtained from reference 7.

The experimental data are presented in tuft grid form, as measured, in figures 7 to 13. The lift coefficients presented were obtained for the tail-off configuration from ref-

erence 7. The nacelles are outlined on the figures to show their location relative to the grid. The upflow angle θ is given at each tuft location.

A summary of the upwash angle ϕ for one tuft is presented in figure 14 as a function of thrust-removed lift coefficient. The geometric characteristics required as input for the program in reference 4 are presented in figure 15.

Comparisons of experimental and calculated results, arranged in essentially a grid form, are presented in figures 16 to 22.

DISCUSSION

Basic Data

The data of figures 7 to 13 show large effects of the wing and engine thrust on the flow field in the vicinity of the nacelles. The upflow angle increased as C_L was increased by increasing α (for example, see figs. 8(a), 8(b), and 8(c)). The upflow angle increased as C_L was increased by increasing C_μ (for example, see figs. 7 to 9). Increasing C_μ from 0 to 2 had a large effect, but a further increase to 4 had much less effect. The maximum value of upflow angle (67.3°) occurred at a position ahead of the lower lip of the nacelle at a lift coefficient of 9.33, a thrust coefficient of 4.0, and angle of attack of 25.7° (fig. 12(c)).

The long tuft mounted on the outboard inlet centerline indicated higher upflow angles for the power-off condition (fig. 10(c)) than those indicated for power-on conditions (figs. 11(b) and 12(b)). The effect (local induced upflow angle due to nacelle flow) would likely be greater (that is the upflow angle would be even smaller) if the flow into the inlet was of the order of the scaled value. The ejector nacelles produce scaled thrust values but produce only approximately one-half of the scaled inlet mass flow. The long tufts below the nacelle centerline indicate very large upflow angles (increasing with power), which could create large engine-face distortion problems.

A summary plot showing the variation with thrust-removed lift coefficient of the upwash angle ϕ between nacelles indicated by one tuft, which is located a distance R behind the leading edge of the inboard nacelle and on the horizontal plane through the centerline of the inboard nacelle, is presented in figure 14. The thrust-removed lift coefficients, which were computed by subtracting the direct-thrust component of lift from the overall lift coefficient, are presented in table II. The figure indicates that, for power-on conditions, the variation of upwash angle ϕ with circulation lift coefficient is essentially the same for different thrust coefficients and flap deflections.

Prediction Calculations

The lift developed by a powered-lift system can be separated into three parts according to the source of the lift: (1) the lift that was produced by the unpowered wing, (2) the

lift due to the component of the jet which has been redirected by the flap system, and (3) the lift due to circulation induced by power. Experimental results indicated that the upwash angle ahead of the wing could be estimated based on thrust-removed lift coefficient.

The thrust-removed lift coefficient (circulation lift coefficient) and wing geometric characteristics were input into the program described in reference 4 to determine the magnitude of circulation.

The geometry required included planform breakpoints, locations of intersections of lines defining the planform (fig. 15), and the chordwise angle-of-attack distribution to represent the slat and flaps on the wing. The program did not account for thickness effects, so the wing section geometry was reduced to a camber line represented by straight lines (fig. 3). Experience with the program in reference 4 indicated that a choice of 10 chordwise vortices equally spaced was a reasonably good representation of the high-lift system, since the planform definition points, as shown in figure 15, could be placed in approximately the right places chordwise without modification of the program. Reference 4 indicates that 20 spanwise stations are adequate. The local angle of attack and circulation were extracted from the program of reference 4 and input into a flow-field program, derived from the vortex-lattice method, to compute the upwash angle ahead of the wing. The experimental angle of attack was then added to the upwash angle to obtain the total upflow angle θ.

Calculated Results

The calculated results are compared to experimental results in figures 16 to 22. The method of calculation appears to be useful, showing fair agreement in the regions away from the nacelle inlet. The calculations near the nacelle inlet are lower than the experimentally measured angles. The program does not include the geometry of the large nacelles or the sink created by the mass flow into the nacelle when powered. These effects must be considered to properly simulate the flow near the nacelles. The calculations for the upflow angle θ outboard of the nacelles agree very well with the experimental data (fig. 22).

CONCLUDING REMARKS

An investigation has been conducted to determine the upwash flow angles in the region of the nacelle inlets of a representative powered-lift transport configuration operating at high lift coefficients. The upwash angles were indicated by tufts and angles measured from photographs. A potential-flow program was used to estimate these flow angles as a comparison.

The results of the investigation indicate that large upflow angles, as high as 67.3^O, exist near the inlets of nacelles located forward and below a wing configured for externally blown flaps. The highest value occurred with flaps deflected for landing at a 25.7^O angle of attack and a thrust coefficient of 4.

The upwash angle was found to be strongly dependent on the circulation or thrust-removed lift, regardless of flap deflection, angle of attack, or thrust coefficient used to generate this circulation lift.

The results of calculations made by a potential-flow method indicated that calculated upflow angles were in fair agreement with experimental values except near the nacelle inlets. The nacelle geometry and sink created by the mass flow into the nacelle when powered must be considered to properly simulate the flow near the nacelle. Calculated upflow angles outboard of the nacelles were in good agreement.

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October 8, 1975

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TABLE I.- TEST CONDITIONS AND CONFIGURATIONS

Figure presenting –		Grid location, $y/(b/2)$	Flap setting, deg	Slat fillers	C_μ	α, deg
Flow data	Calculated results					
7	16	0.338	0,20,40	On	0	0.5, 6.6, and 12.5
8	17	.338	0,20,40	On	2.0	0.5, 12.7, and 24.8
9	18	.338	0,20,40	On	4.0	0.6, 12.7, and 24.8
10	19	.338	15,35,55	Off	0	0.5, 6.7, and 12.8
11	20	.338	15,35,55	Off	2.0	0.9, 12.4, and 25.7
12	21	.338	15,35,55	Off	4.0	1.4, 13.5, and 25.7
13	22	.502	15,35,55	On	0	-0.8, 9.0, and 17.1

TABLE II.- SUMMARY OF DIRECT THRUST
CONTRIBUTION CALCULATIONS

C_μ	α, deg	δ_j, deg	η	C_L	$C_{L,\Gamma}$
Take-off flaps					
2.0	0.5	22.76	0.8755	2.93	2.24
2.0	12.7	22.76	.8755	5.00	3.98
2.0	24.8	22.76	.8755	6.25	4.96
4.0	.6	20.66	.8903	3.56	2.27
4.0	12.7	20.66	.8903	5.90	3.94
4.0	24.8	20.66	.8903	7.90	5.36
Landing flaps					
2.0	0.9	44.53	0.7819	4.90	3.79
2.0	12.4	44.53	.7819	6.72	5.41
2.0	25.7	44.53	.7819	6.75	5.28
4.0	1.4	42.45	.7935	6.00	3.80
4.0	13.5	42.45	.7935	8.40	5.77
4.0	25.7	42.45	.7935	9.33	6.39

Wing:

Airfoil section, root	NACA 63_2A214
Airfoil section, tip	NACA 63_2A211
Area, sq m (sq ft)	.499 (5 374)
Mean aerodynamic chord, m (ft)	.278 (.913)
Span, m (ft)	1.905 (6 250)
Aspect ratio	7.269

Vertical tail:

|	
Airfoil section	NACA 0012
Area, sq m (sq ft)	183 (1.968)
Mean aerodynamic, m (ft)	.374 (1228)
Span, m (ft)	493 (1617)
Aspect ratio	1.328

Figure 1.- STOL model geometric characteristics. Dimensions are in cm (in.) unless otherwise noted.

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(a) Side view.

Figure 2.- Tuft grid mounted between nacelles of STOL model. 50° slats with fillers and flaps at 15°, 35°, 55°.
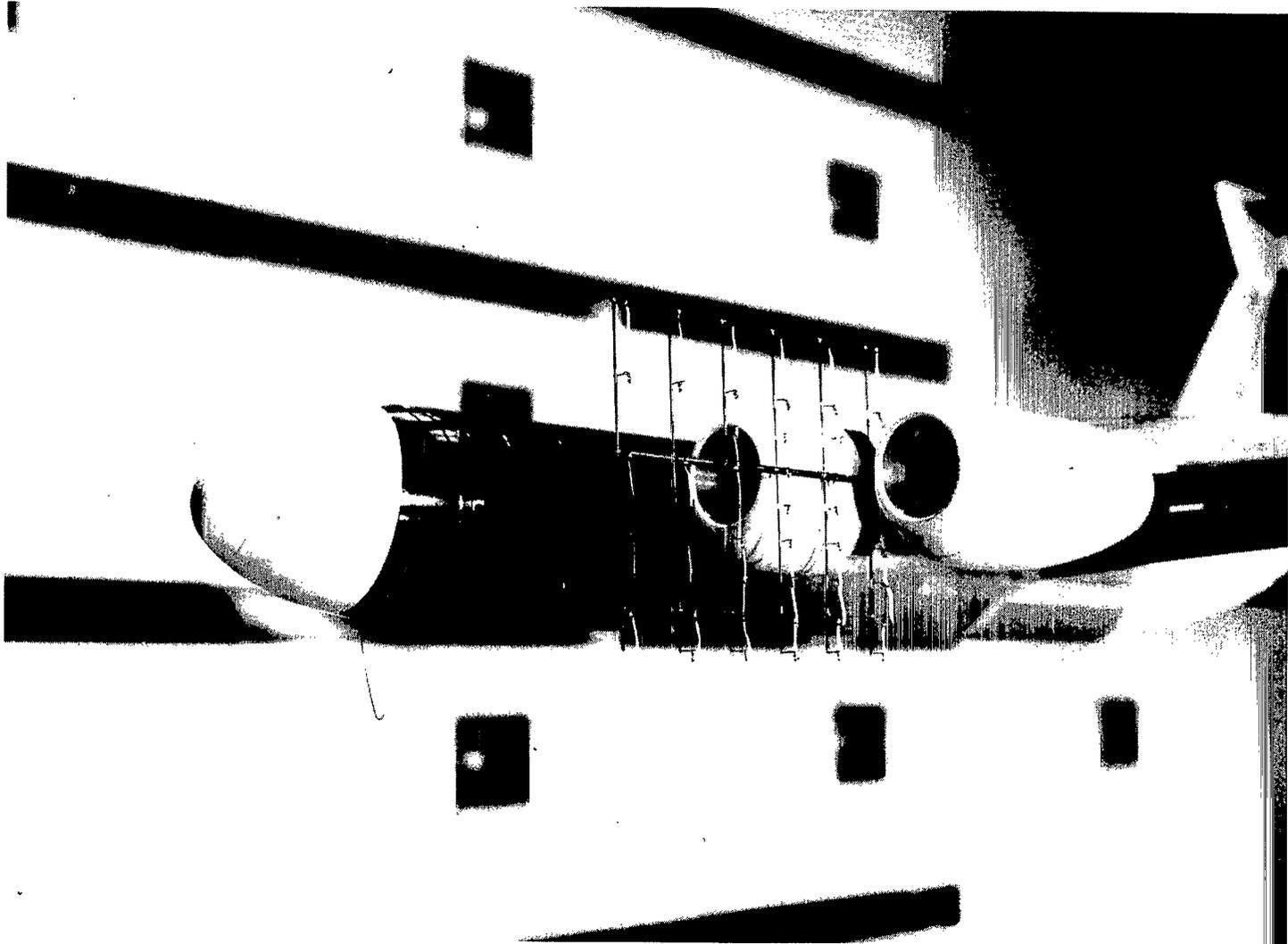
L-72-3527

(b) Front quarter view.

Figure 2.- Concluded.

○ Bound vortex

□ Control point for camber slope
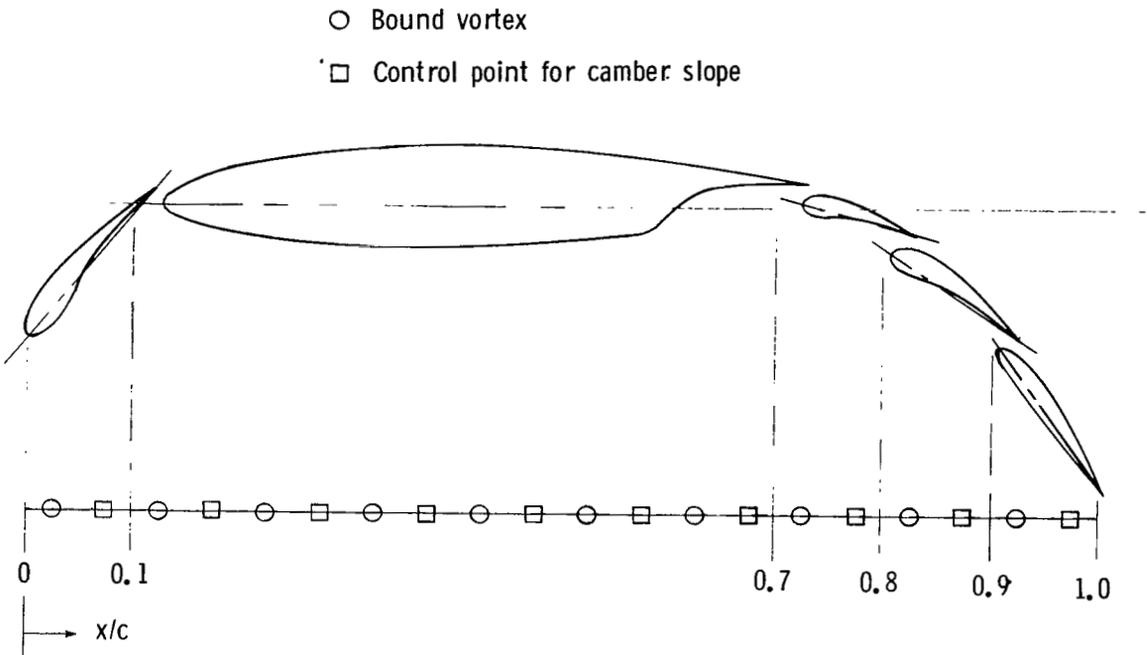
(a) Landing configuration. $15^{\circ},35^{\circ},55^{\circ}$ flap deflection and 50° slat deflection.
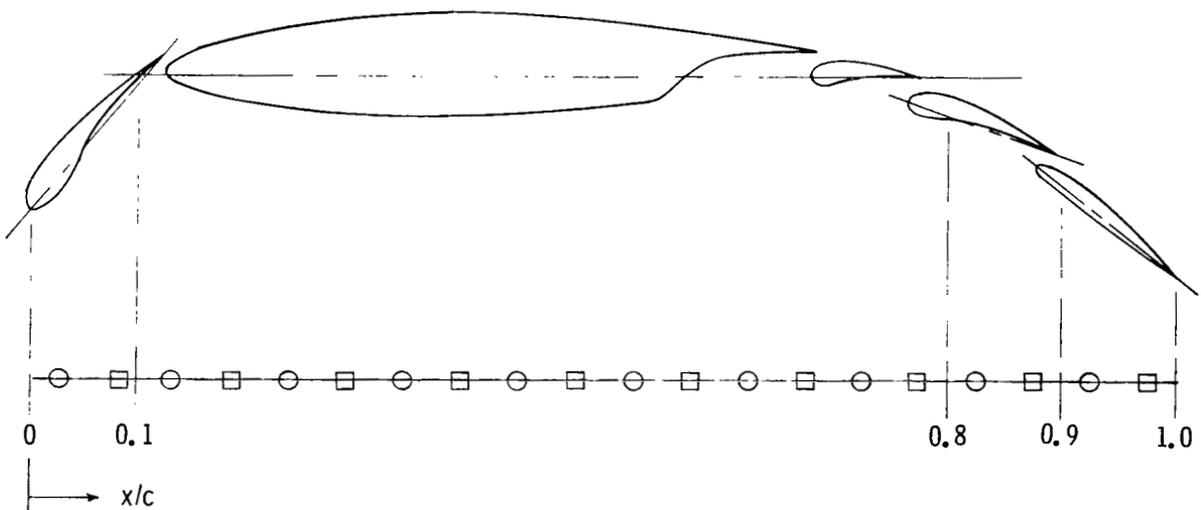
(b) Take-off configuration. $0^{\circ},20^{\circ},40^{\circ}$ flap deflection and 50° slat deflection.

Figure 3.- Comparison of flapped wing sections and vortex-lattice representations used in calculations.

2.109$\bar{c}$

0.338$\frac{b}{2}$

0.420$\frac{b}{2}$

0.258$\bar{c}$ 1.298$\bar{c}$

1.556$\bar{c}$

$\bar{c}$=27.81(10.95)

Spanwise tuft locations

• Tufts located between nacelles

○ Tufts on vertical plane through nacelle $\mathcal{C}$

$\frac{b}{2}$ = 95.25 (37.500)

Tuft spacing = Radius of upper part of nacelle
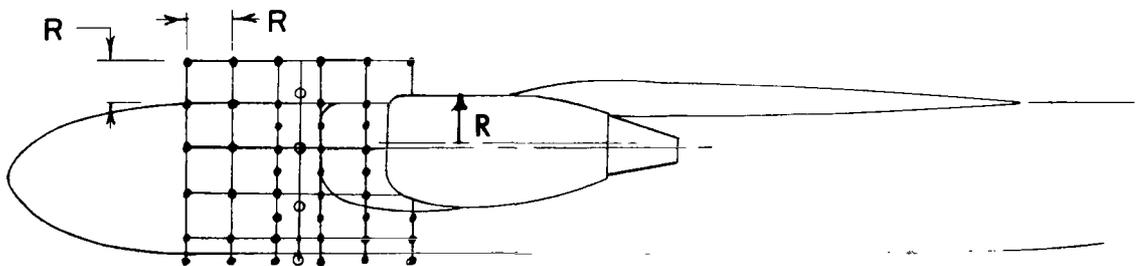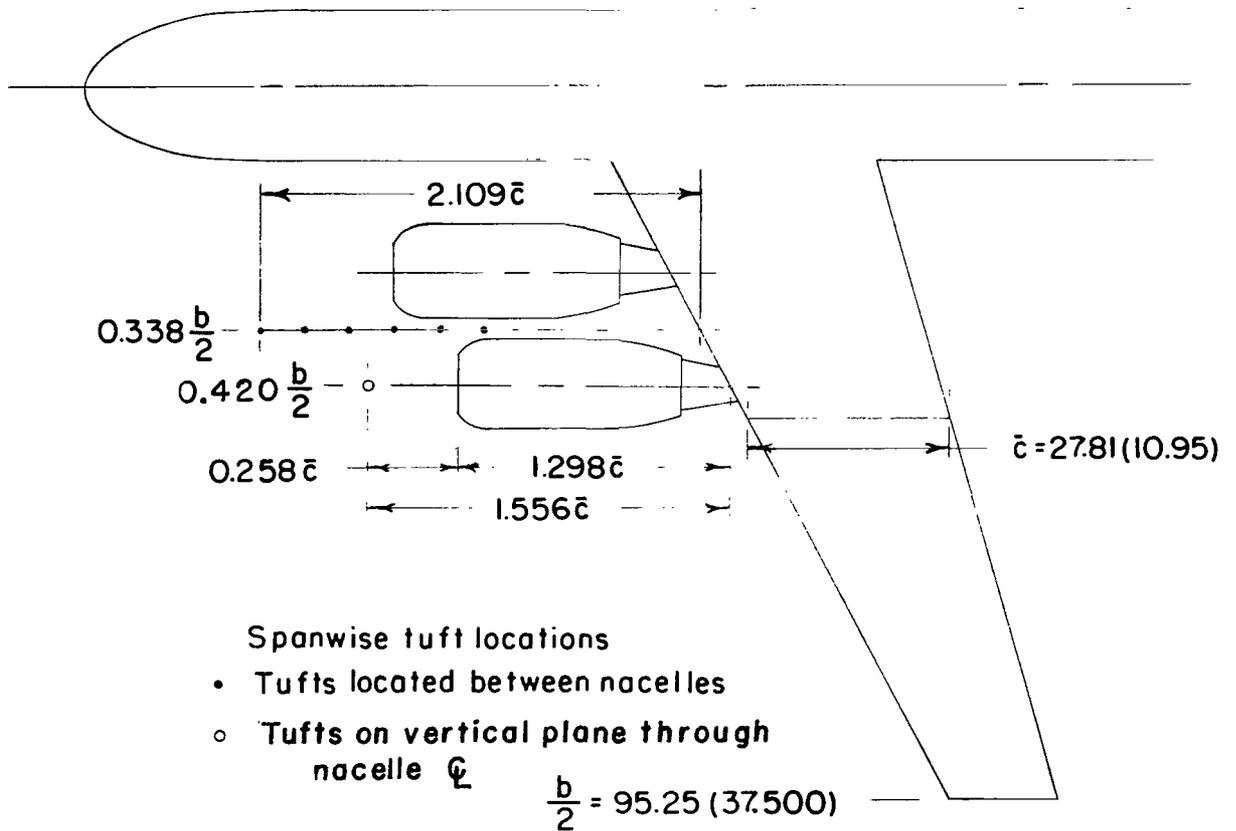
R = 0.065 $\frac{b}{2}$

(a)   0.338$\frac{b}{2}$ location.

Figure 4.- Location of tufts. Dimensions are in cm (in.) unless otherwise noted.

- Tuft locations

$$0.502 \frac{b}{2}$$

$$2.109 \, \bar{c}$$

$$\bar{c} = 27.81 (10.95)$$

$$\frac{b}{2} = 95.25 \, (37.500)$$
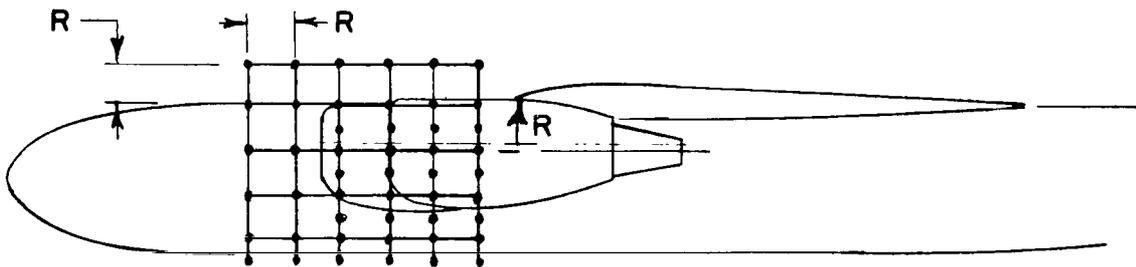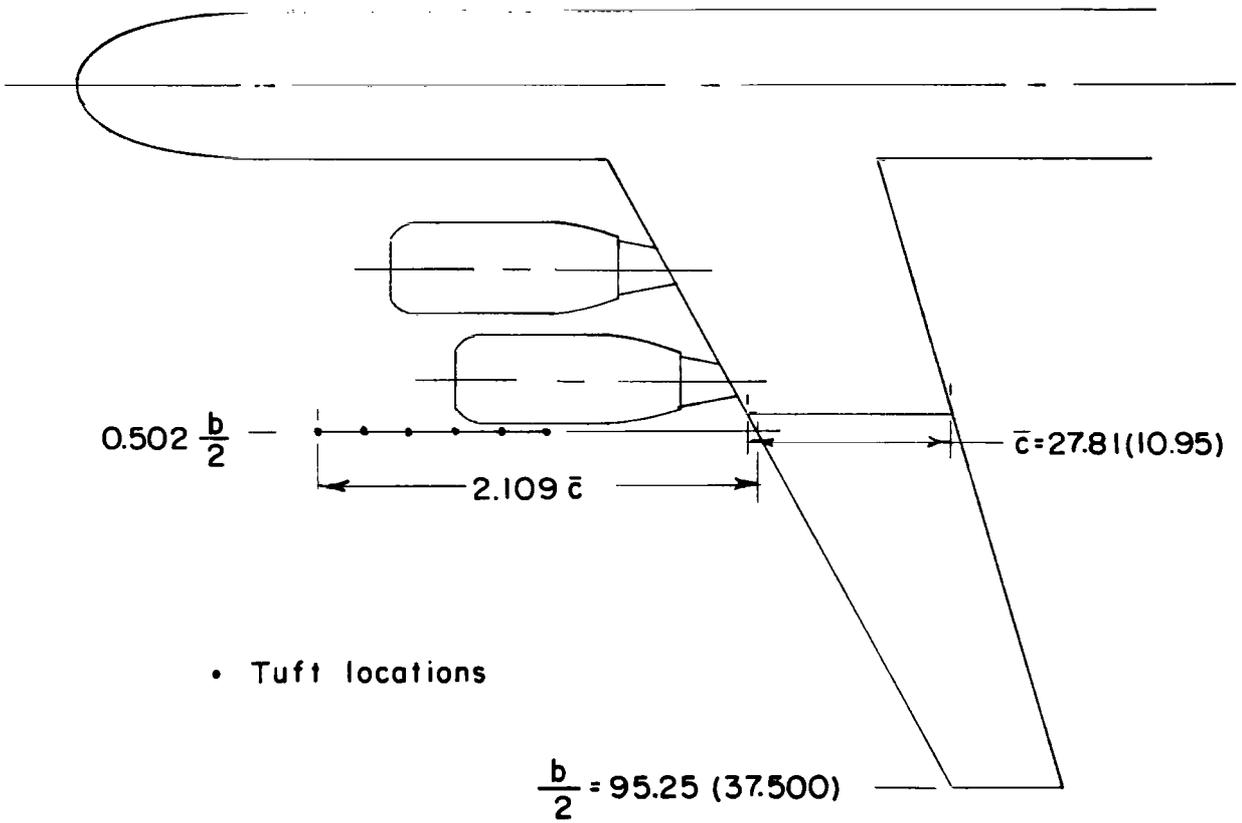
Tuft spacing = Radius of upper part of nacelle

$$R = 0.065 \, \frac{b}{2}$$

(b) $0.502 \frac{b}{2}$ location.

Figure 4.- Concluded.
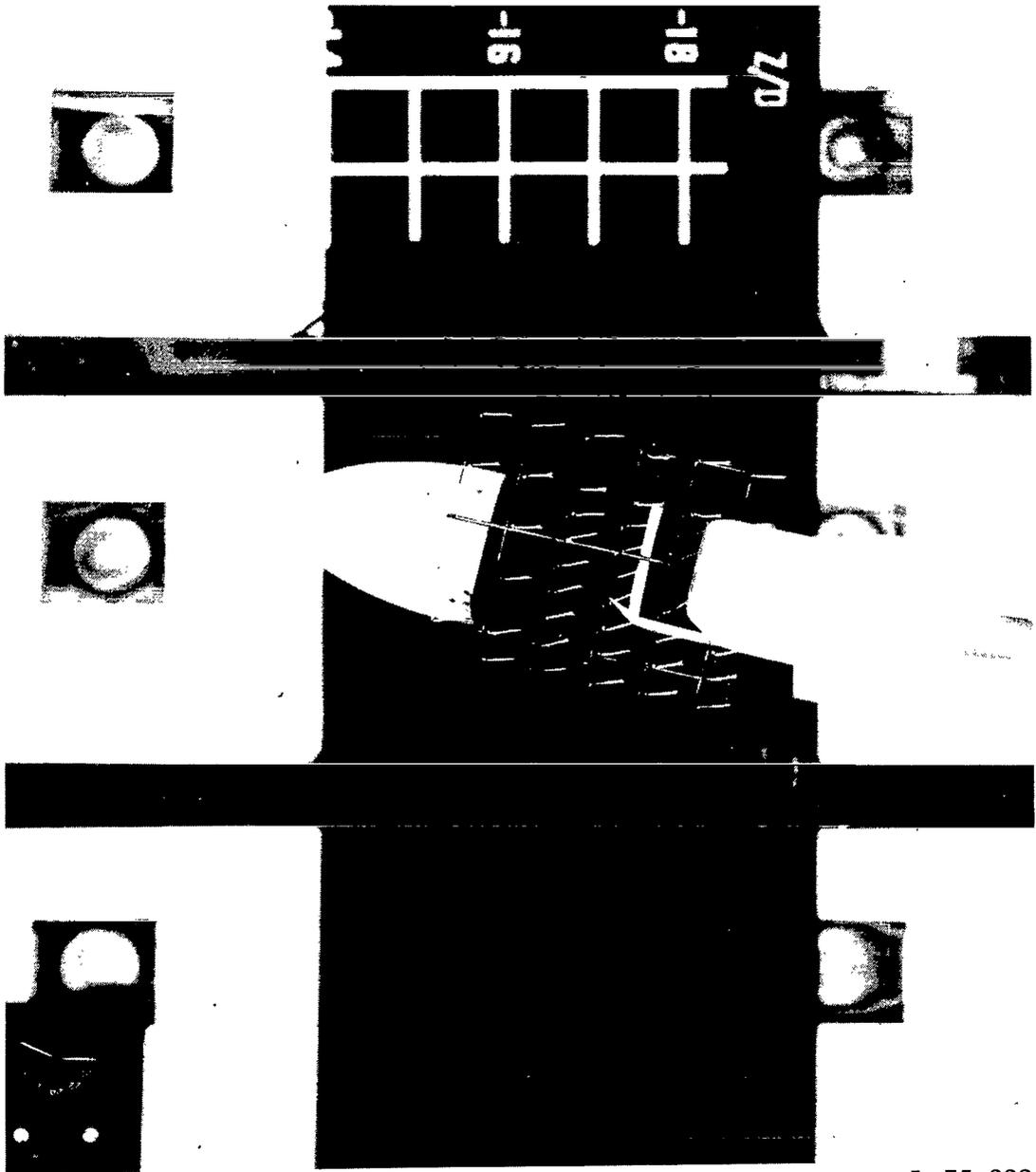
Figure 5.- Example of tuft photographs.   Tuft grid located at $0.338 \frac{b}{2}$; flaps at $0^O, 20^O, 40^O$; $C_\mu = 4.0$; slat fillers on.

L-75-222

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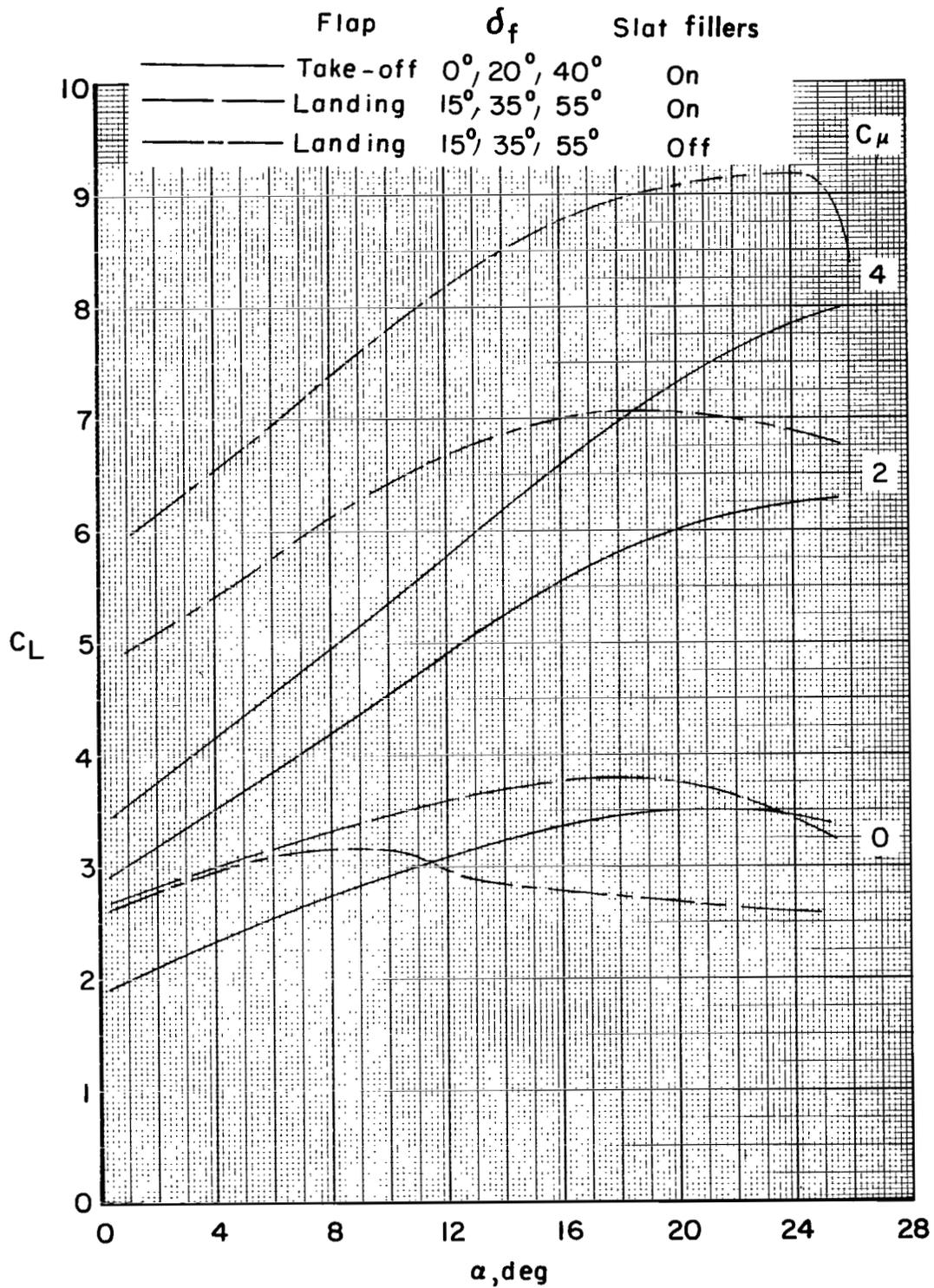
Figure 6.- Tail-off lift characteristics.

- Tufts in a chordwise plane located
  between the port nacelles

0.7	1.1	2.2	2.3	2.1	2.3

1.9	1.9	6.0	5.9	8.9	

9.2   8.9   9.9

1.9	1.0	4.5	3.9	9.2

-2.6   0   0

3.8	-0.2	-2.0	-2.9	-3.0

-2.6   -3.7   -3.1   2.1

-1.1	-1.2	-1.2	-4.7	-5.6	-4.0

-1.1   -2.5   -0.1   0.7   1.6

R

$\frac{C}{L}$

|←—R—→|

——→ V

(a) $\alpha = 0.5^{O}$; $C_L = 1.90$.

Figure 7.- Upflow angle, deg, between nacelles as shown by a tuft grid
located at $0.338 \frac{b}{2}$. Flaps at $0^O, 20^O, 40^O$; $C_\mu = 0$; slat fillers on.

• Tufts in a chordwise plane located
between the port nacelles

6.8　　11.3　　11.2　　13.4　　12.6　　8.3

10.7　　13.3　　16.2　　16.4　　16.5　　13.1

　　　　　　11.1　　20.0　　19.1

R

9.3　　8.7　　15.9　　16.2　　27.5

$\mathcal{C}$_L

　　　　　　11.6　　16.1　　19.0

8.8　　7.0　　6.6　　8.5　　7.5

　　　　　　5.1　　3.0　　3.0　　10.2

6.4　　8.0　　6.8　　5.6　　7.2

5.0　　4.9　　4.4　　4.4　　6.2

|←— R —→|

——→ V

(b)　$\alpha = 6.6^O$;　$C_L = 2.60$.

Figure 7.- Continued.

• Tufts in a chordwise plane located
  between the port nacelles

15.6   17.5   18.1   18.6   17.9   15.3

18.6   18.6   22.5   22.3   17.1   22.7

   23.4   20.3   34.1

11.4   17.5   30.3   21.9   37.5

   22.0   26.0   30.9

17.9   16.1   20.3   21.7   20.1

   15.9   12.8   12.3   15.4

16.8   16.0   17.5   12.0   12.2   12.9

   12.2   11.7   11.5   10.5   10.9

R

$\mathcal{C}_L$

|← R →|

V
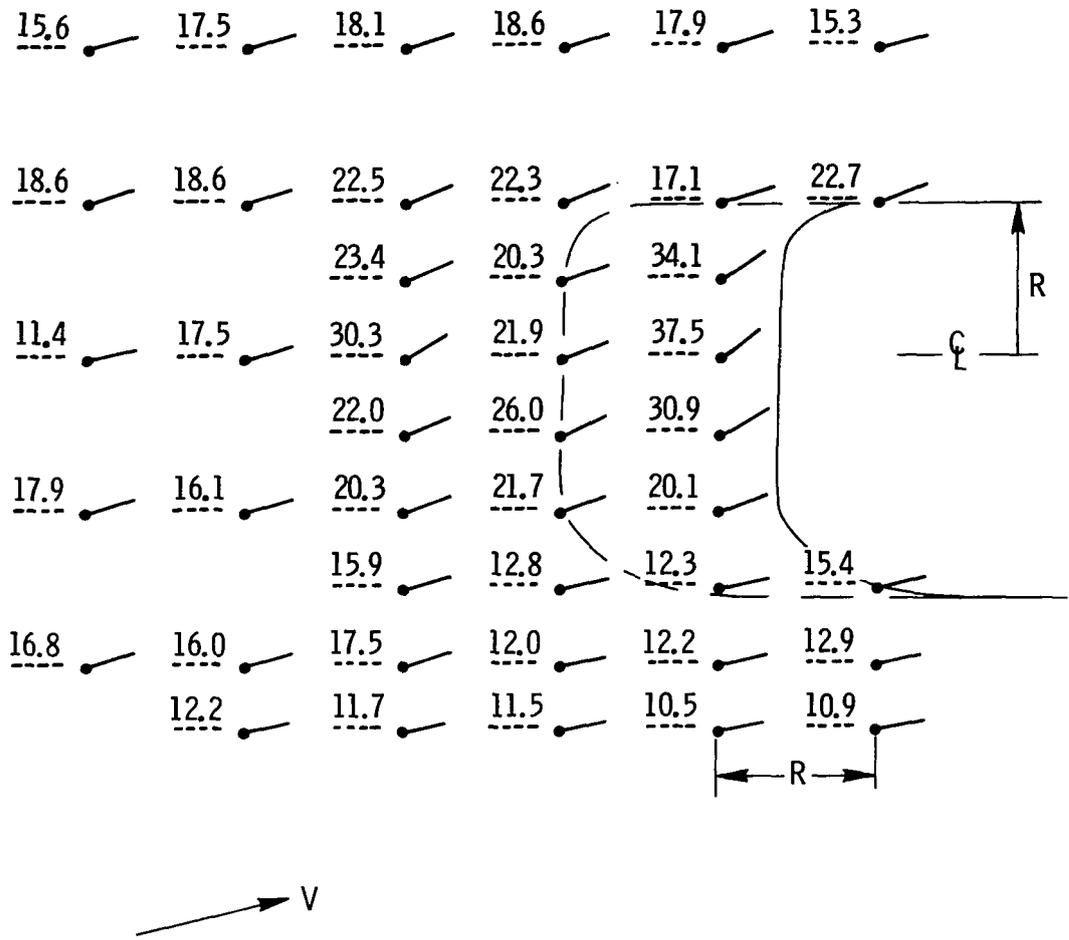
(c) $\alpha = 12.5^{\circ}$; $C_L = 3.10$.

Figure 7.- Concluded.

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• Tufts in a chordwise plane located
between the port nacelles

-0.5 ____   0.2 ____   0.5 ____   0.1 ____   -0.7 ____   -0.5 ____

8.1 ____   2.6 ____   -0.2 ____   -0.7 ____   -1.6 ____

                          2.0 ____   0.9 ____   20.5 ____

0.5 ____   1.0 ____   4.5 ____   7.1 ____   16.1 ____   ── ₵

                          8.0 ____   5.5 ____   12.1 ____

1.0 ____   1.3 ____   4.9 ____   3.3 ____   2.7 ____

                          2.8 ____   2.3 ____   2.3 ____   4.2 ____

1.9 ____   2.5 ____   5.2 ____   0.1 ____   0.4 ____   5.9 ____

                          0.2 ____   1.0 ____   2.1 ____   2.4 ____   3.1 ____

                                                |←─R─→|

─────────▶ V
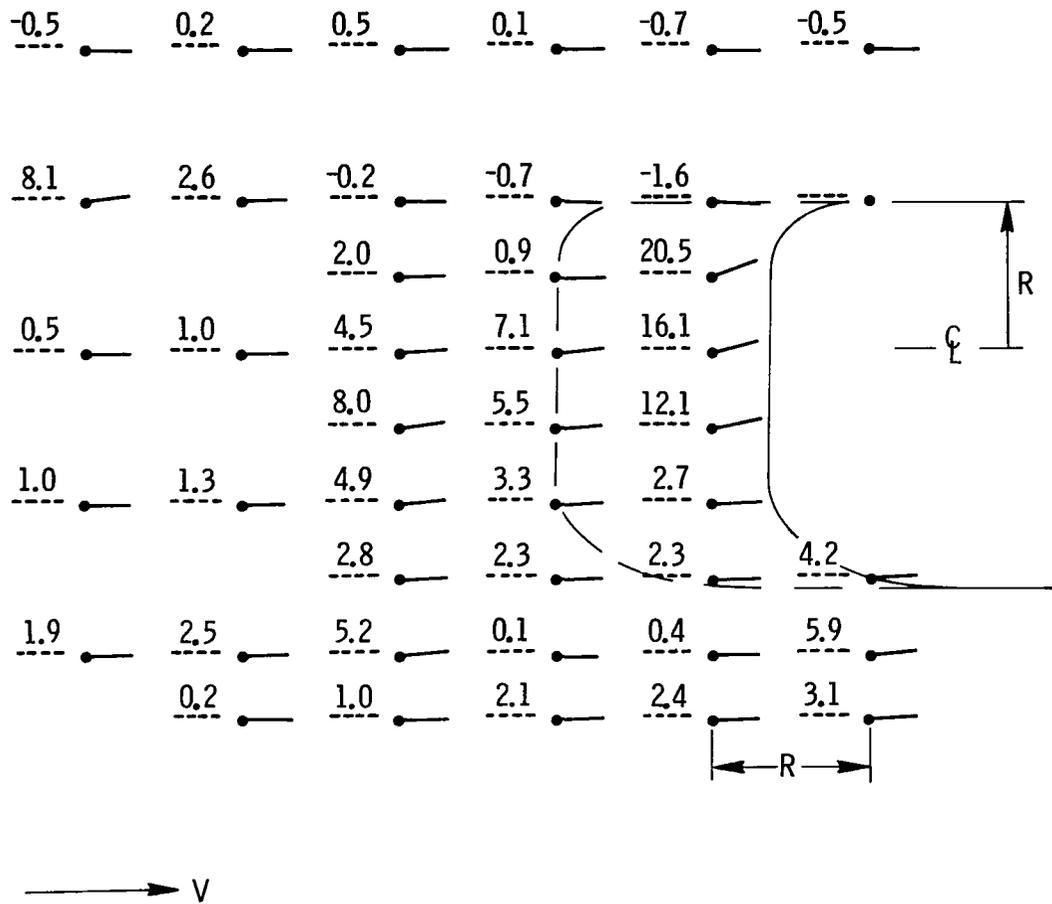
(a) $\alpha = 0.5^{o}$; $C_L = 2.93$.

Figure 8.- Upflow angle, deg, between nacelles as shown by a tuft grid
located at $0.338\frac{b}{2}$. Flaps at $0^{o}, 20^{o}, 40^{o}$; $C_\mu = 2.0$; slat fillers on.

• Tufts in a chordwise plane located
between the port nacelles

12.5   13.8   14.0   13.6   12.2   11.5

15.2   14.3   13.0   11.9   12.3

        17.2   16.4   25.5

15.5   15.4   23.1   28.1   35.5

        24.3   32.4   40.4   R

22.7   18.3   25.9   30.2   35.2 $\mathsf{C_L}$

        23.1   23.3   24.2   23.0

17.9   19.8   22.7   21.1   22.3   18.2

        15.0   15.0   17.1   13.2   13.0

|←— R —→|

V

(b) $\alpha = 12.7^{O}$; C_L = 5.00.

Figure 8.- Continued.

- Tufts in a chordwise plane located
  between the port nacelles

23.4   25.4   25.6   24.3   23.3   22.4

27.5   27.5   25.4   25.1   22.5   29.6

           29.2   28.8   37.5   R

28.6   27.6   34.7   40.0   51.8 $-$ ₵

           33.6   49.1   58.2

30.2   31.3   39.8   48.4   55.8

           35.8   42.6   49.3   35.7

30.0   34.2   35.5   34.4   33.3   29.6

           31.6   29.9   32.3   30.2   27.9

                                |←—R—→|

V

(c) $\alpha = 24.8^{\circ}$; $C_L = 6.25$.

Figure 8.- Concluded.

- Tufts in a chordwise plane located
  between the port nacelles
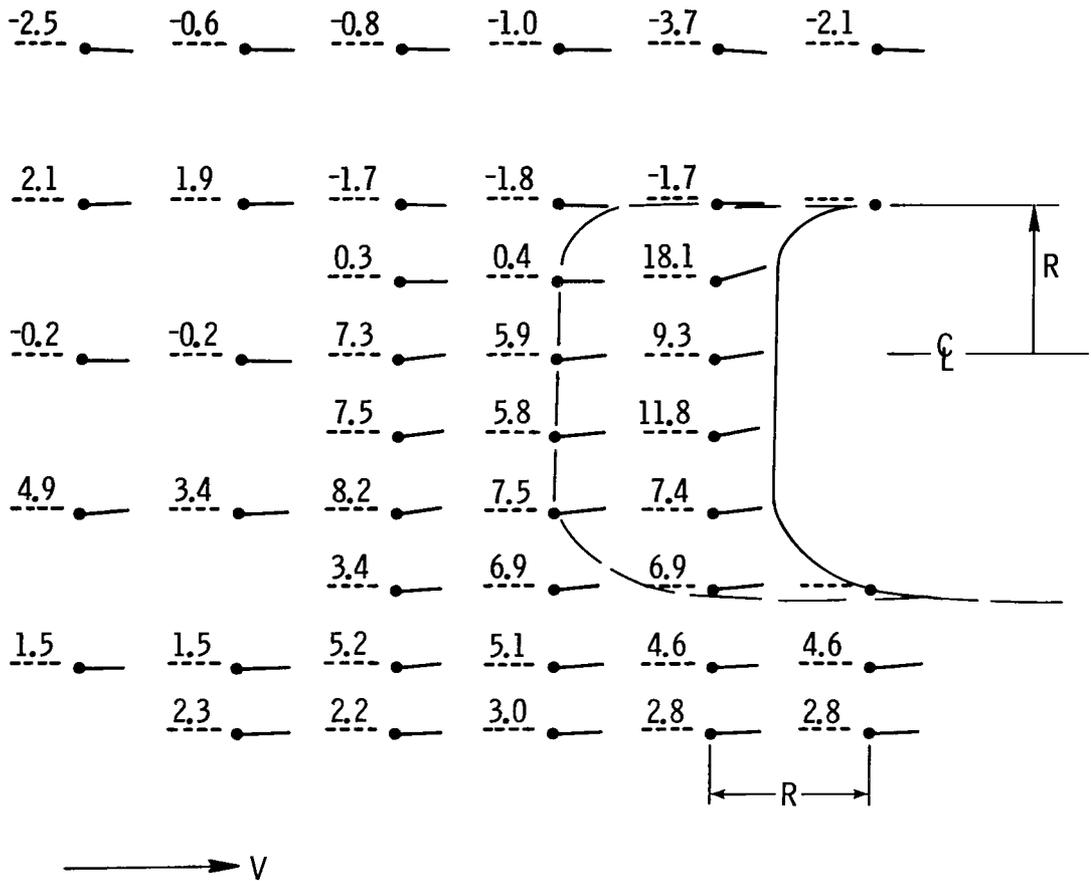
(a) $\alpha = 0.6^{\circ}$; $C_L = 3.56$.

Figure 9.- Upflow angle, deg, between nacelles as shown by a tuft grid
located at $0.338\frac{b}{2}$. Flaps at $0^{\circ}, 20^{\circ}, 40^{\circ}$; $C_{\mu} = 4.0$; slat fillers on.

• Tufts in a chordwise plane located
  between the port nacelles

10.5	14.3	12.5	11.9	12.5	10.5

14.3	14.9	12.4	13.7	13.0	

14.5 13.6 29.3

14.9 23.3 23.9 35.1

22.5 29.4 39.6

22.8 17.2 26.2 22.8 40.7

23.3 27.0 25.9 24.2

16.7 20.0 25.3 21.2 22.6 21.3

16.0 16.5 17.5 18.1 16.3

R

C̵L

R

→ V
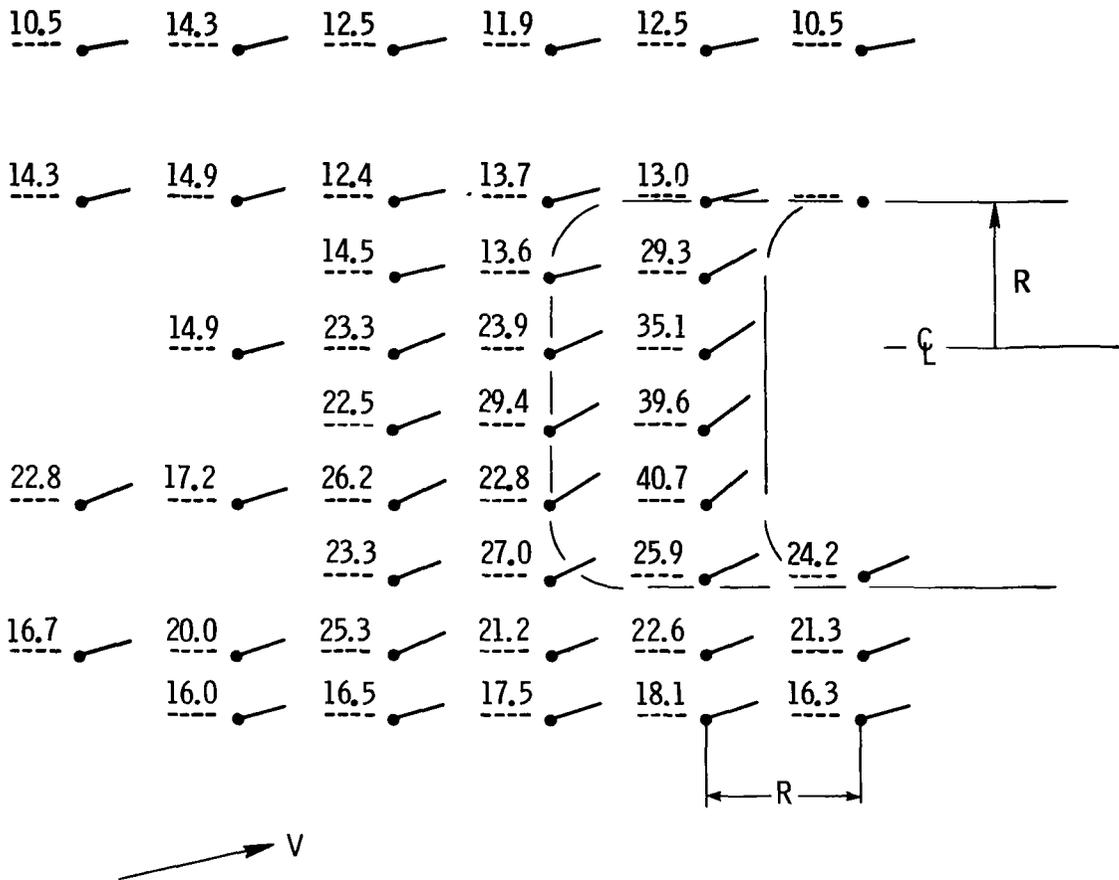
(b) $\alpha = 12.7^{\circ}$; $C_L = 5.90$.

Figure 9.- Continued.

• Tufts in a chordwise plane located
between the port nacelles

25.3   27.5   26.8   26.8   22.8   22.7

27.3   27.8   24.3   24.3   22.5   26.1
                    27.0   26.1   37.4
29.2   28.8   33.7   37.4   54.8
                    34.6   50.1   59.4
31.3   33.0   36.7   49.0   65.3
                    38.4   45.9   55.3   38.3
33.9   35.2   36.9   40.9   40.4   35.0
          33.2   32.7   36.8   35.8   30.1

R

C
L

R

V
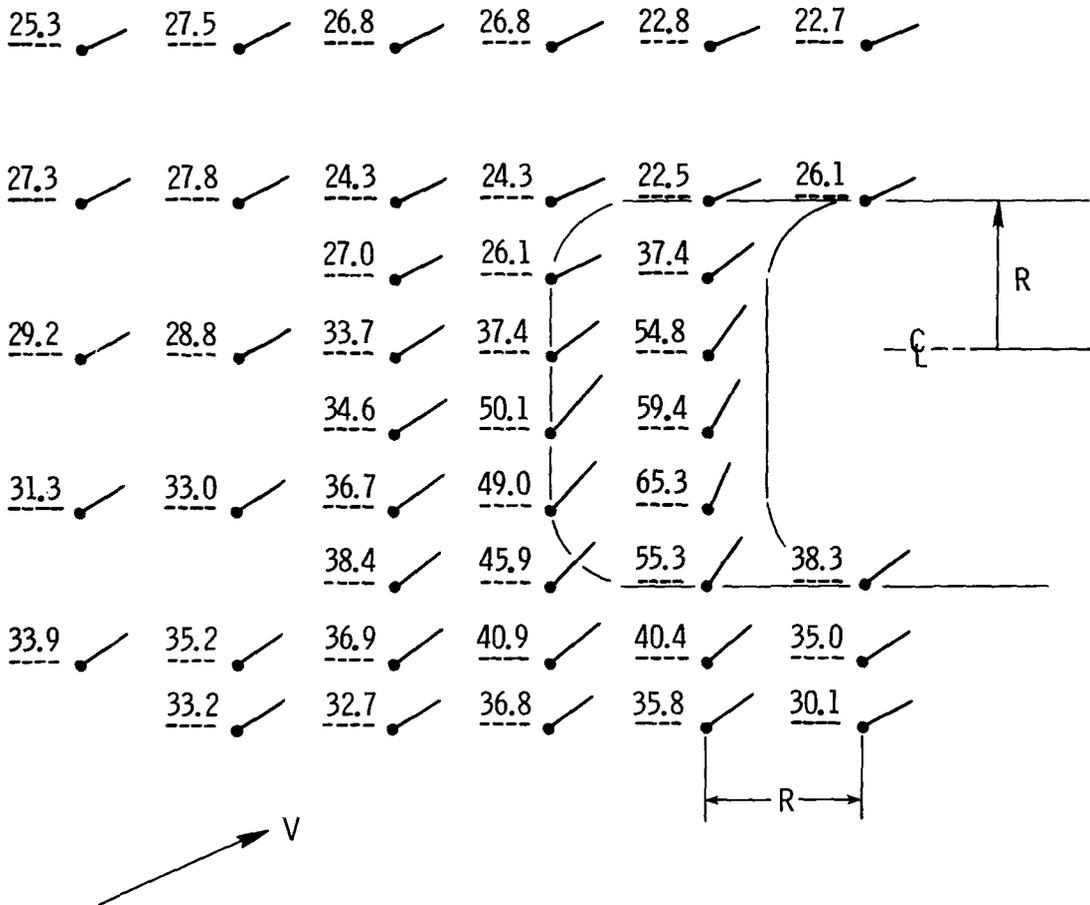
(c) $\alpha = 24.8^{O}$; $C_L = 7.90$.

Figure 9.- Concluded.

- Tufts in a chordwise plane located between the port nacelles
- Tufts in vertical plane of centerline of outboard nacelle
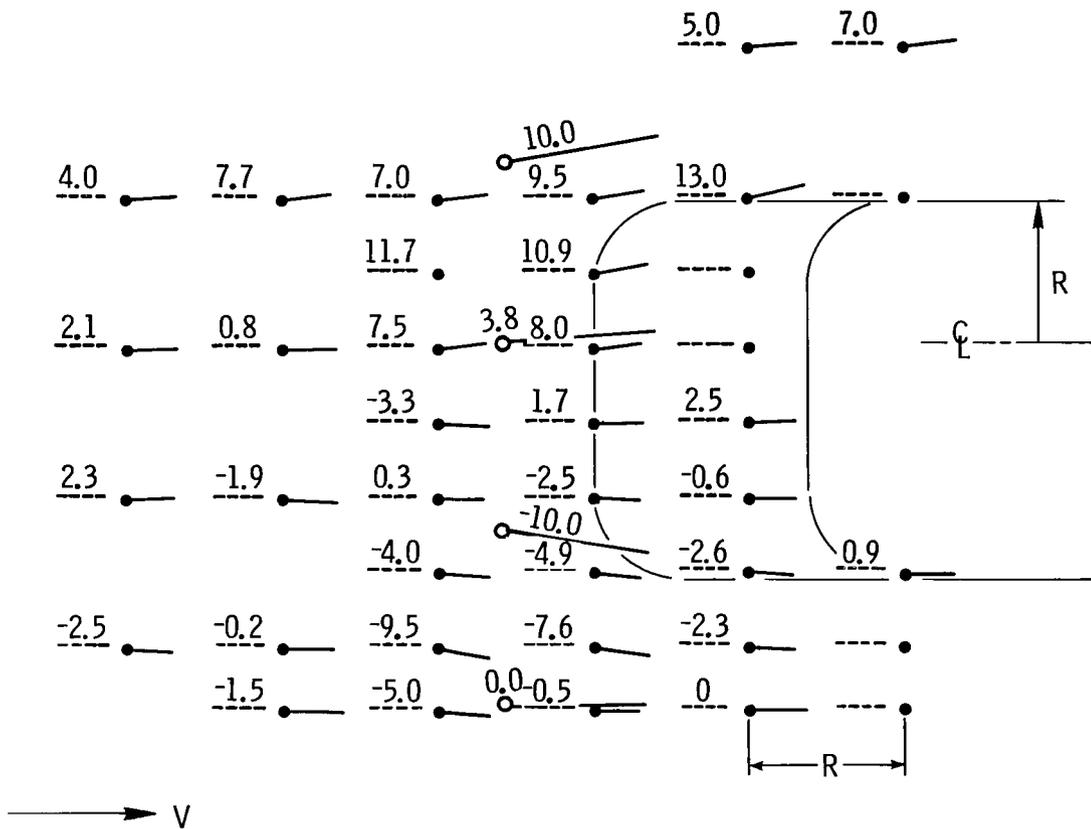
(a) $\alpha = 0.5^{\circ}$; $C_L = 2.6$.

Figure 10.- Upflow angle, deg, between nacelles as shown by a tuft grid located at $0.338\frac{b}{2}$. Flaps at $15^{\circ}, 35^{\circ}, 55^{\circ}$; $C_{\mu} = 0$.

- Tufts in a chordwise plane located
between the port nacelles
- Tufts in vertical plane of centerline
of outboard nacelle

15.0

12.1   12.1   15.1   18.4   19.5

21.1   19.9   19.7

20.7

13.0   11.0   19.7   17.0   30.7

10.0   16.2   23.5

11.5   8.7   11.1   9.7   10.2

2.2

7.2   4.4   4.2   11.1

1.7   6.2   0.8   4.2   7.7

6.0   5.2   6.2   5.7

R

R

$\mathcal{C}_L$

V
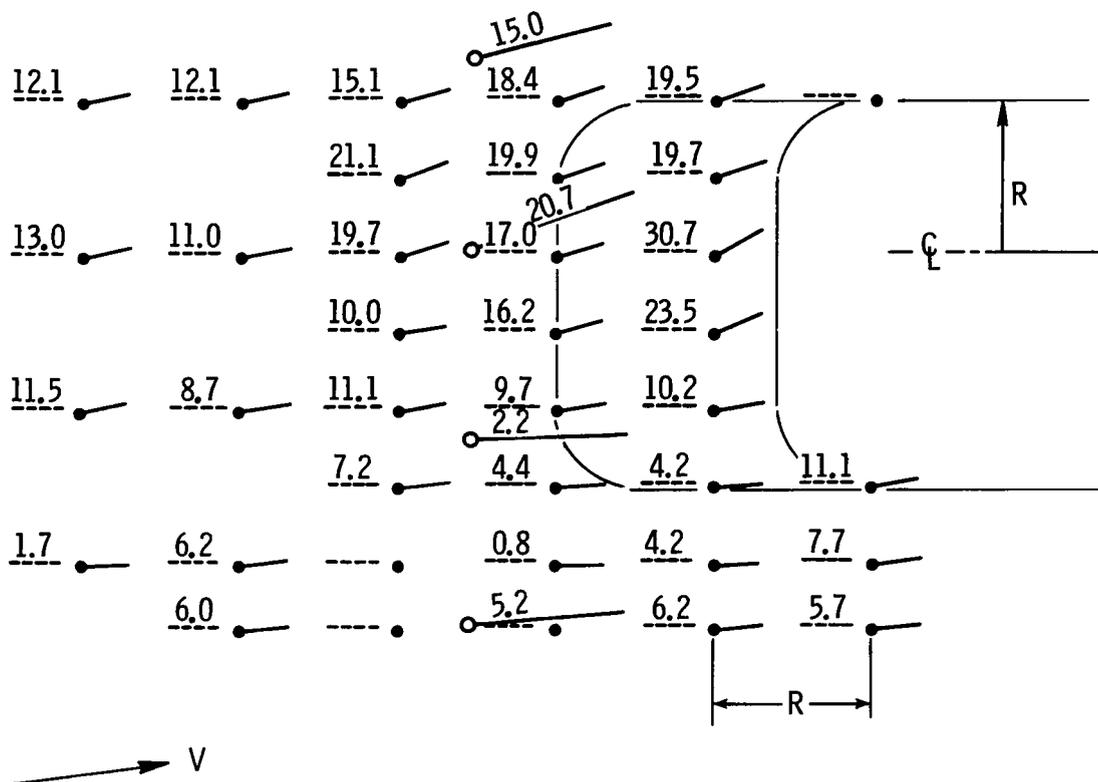
(b) $\alpha = 6.7^{\circ}$; $C_L = 3.1$.

Figure 10.- Continued.

28

• Tufts in a chordwise plane located
between the port nacelles

o Tufts in vertical plane of centerline
of outboard nacelle

17.4

18.8

19.6

24.2   22.3   28.8

17.8   17.2   28.3   27.2   23.6   31.8   R

23.2   24.6   30.8

17.6   16.1   22.3   21.4   20.8

16.8

15.2   11.1   12.8   17.8

13.4   15.6   9.0   10.0   14.3

12.3   11.3 10.9   10.6   11.3

R

V
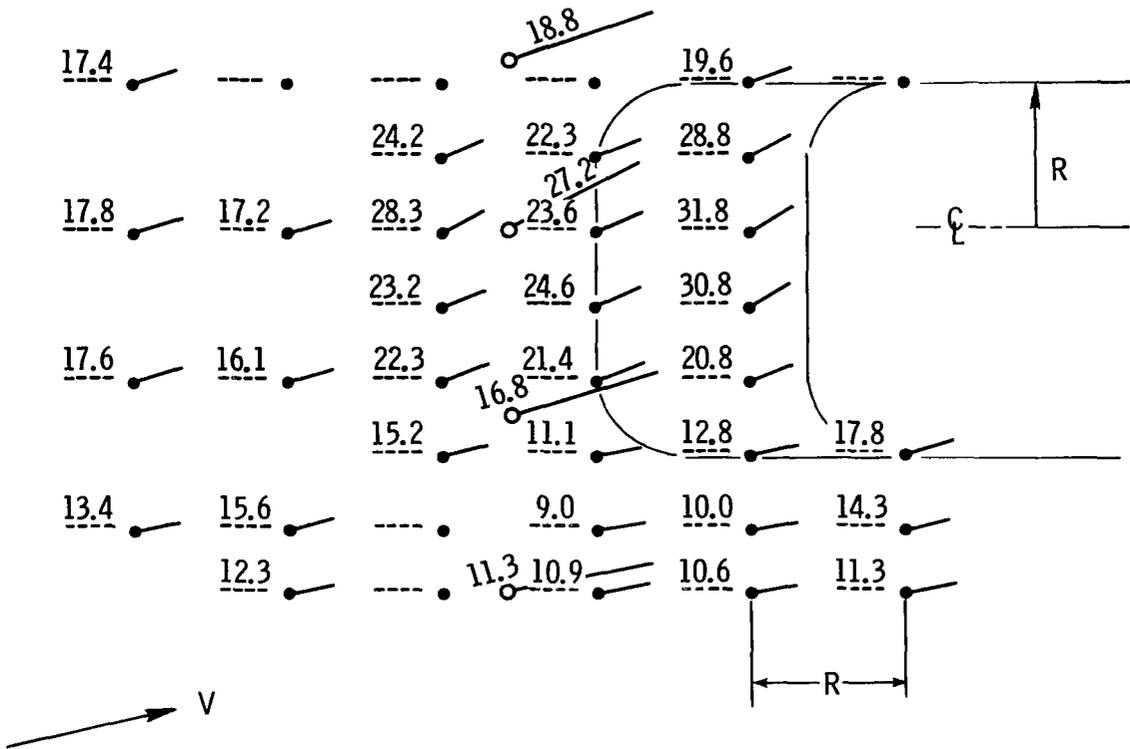
(c) $\alpha = 12.8^{o}$; $C_L = 2.9$.

Figure 10.- Concluded.

29

• Tufts in a chordwise plane located
between the port nacelles

o Tufts in vertical plane of centerline
of outboard nacelle

6.4   5.2   2.4   o–2.4 $\frac{-2.4}{}$ 5.9   R

              5.4   5.2   12.9

7.3   3.7   7.9   1.9   22.4   –$\mathcal{C}$

              7.9   10.3   25.9

5.3   5.0   10.4   11.4   15.9
                   20.4
              7.9   6.9   8.2   9.4

-1.6   5.3   4.9

                   3.4

———▶ V
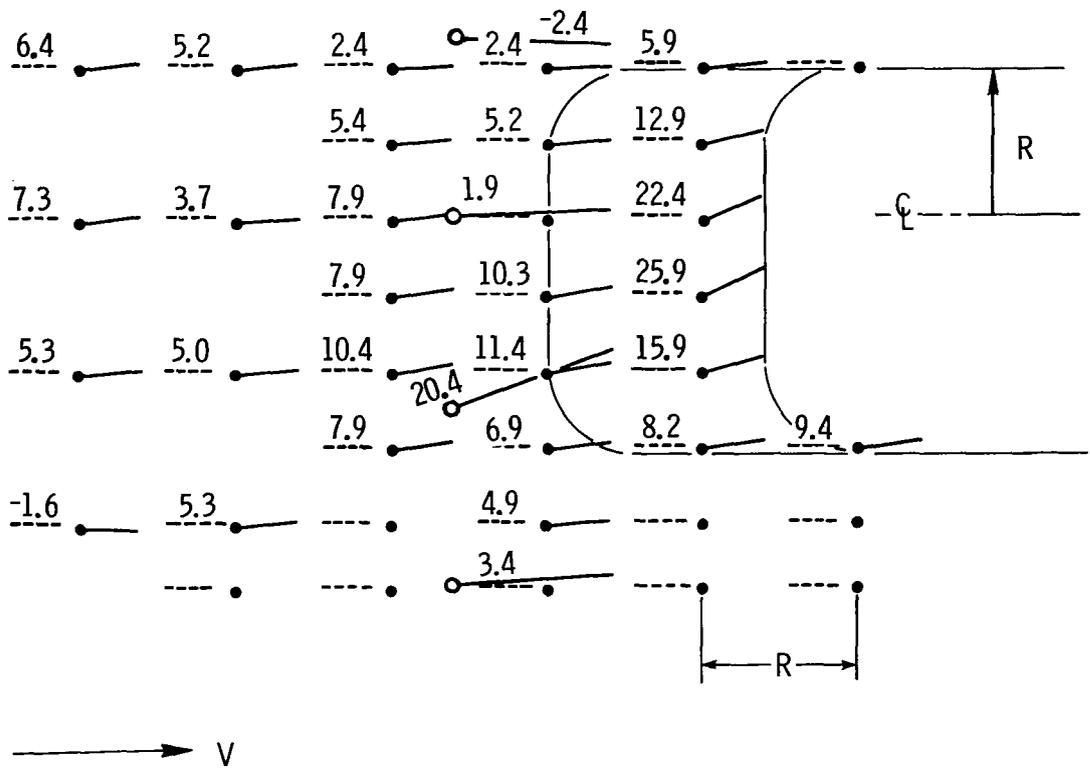
(a) $\alpha = 0.9°$; $C_L = 4.90$.

Figure 11.- Upflow angle, deg, between nacelles as shown by a tuft grid
located at $0.338\frac{b}{2}$. Flaps at $15°,35°,55°$; $C_\mu = 2.0$.

30

- Tufts in a chordwise plane located
  between the port nacelles

o Tufts in vertical plane of centerline
  of outboard nacelle
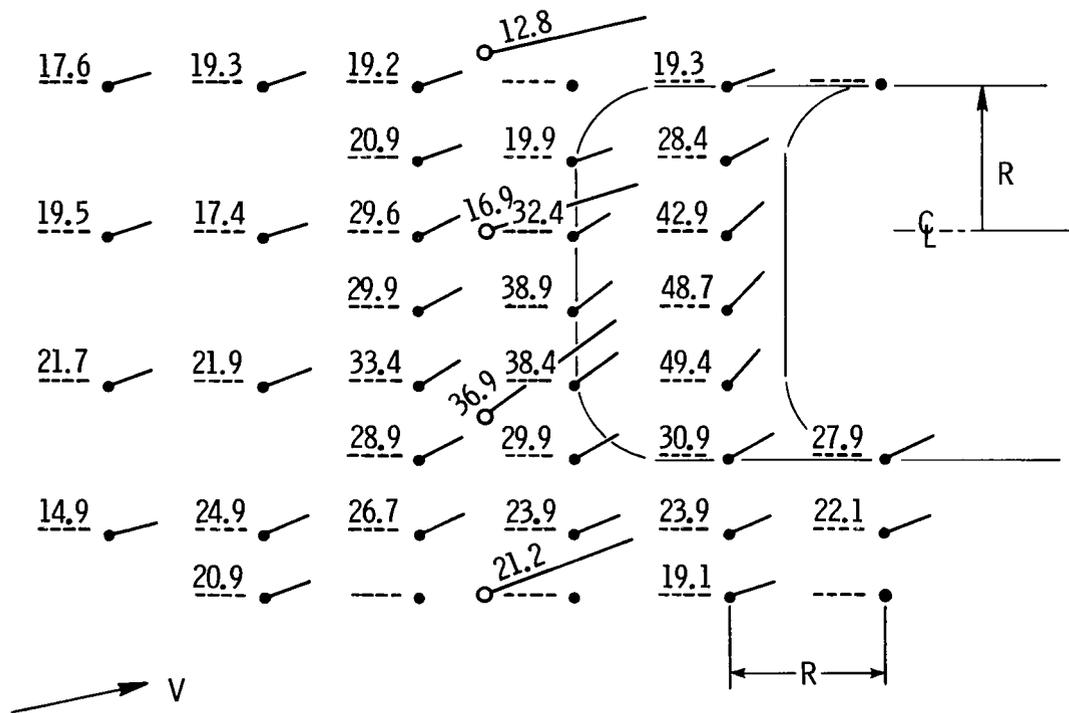
(b) $\alpha = 12.4^{\circ}$; $C_L = 6.72$.

Figure 11.- Continued.

31.7   31.1   30.7   27.3   23.4

28.2   30.3   41.2

29.3

31.1   31.0   39.5   39.7   60.2 $\mathcal{C}$

37.6   51.2   64.9

32.7   34.4   46.2   53.7   66.7

43.2

43.2   47.4   59.7

39.2   45.7   46.7   46.7   36.9

41.2   40.7   39.2   33.3

55.7

R

V
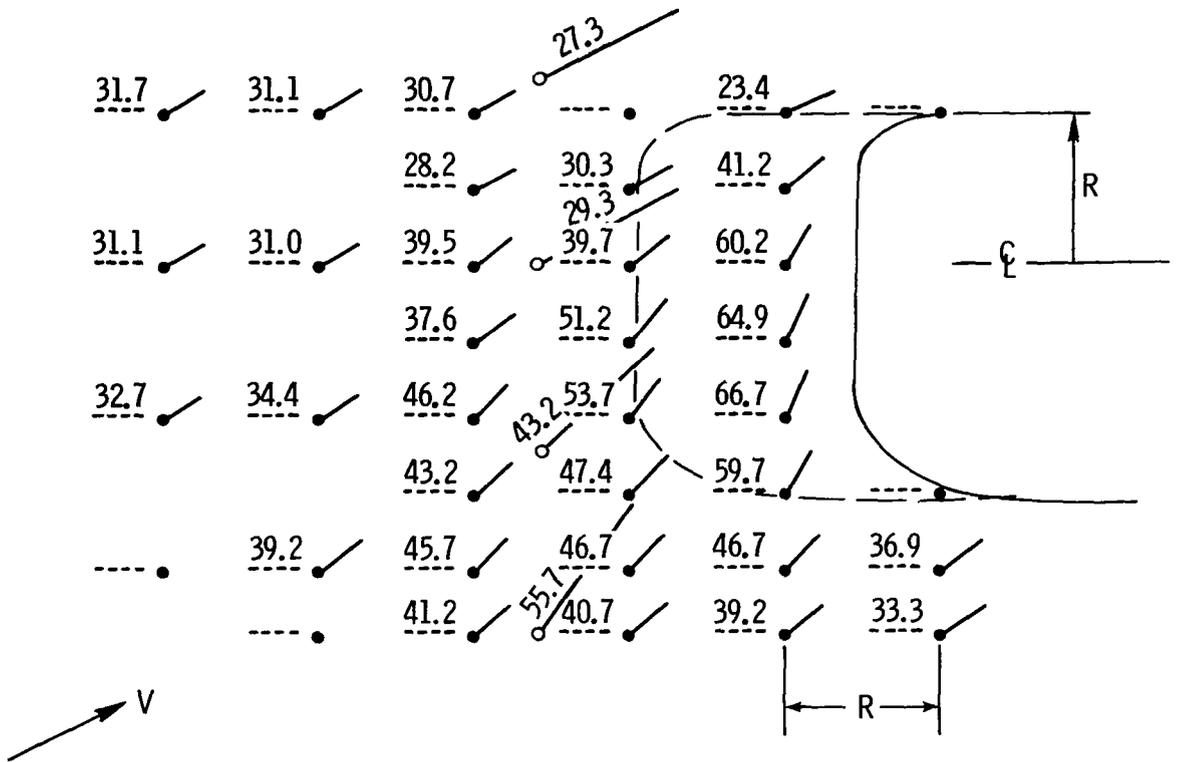
(c) $\alpha = 25.7^{o}$; $C_L = 6.75$.

Figure 11.- Concluded.

• Tufts in a chordwise plane located
  between the port nacelles

○ Tufts in vertical plane of centerline
  of outboard nacelle

4.3   5.3   1.8   ○1.4 -8.6   1.4

2.4   4.9   28.6   R

6.4   4.8   15.9   12.4 |2.7   23.9   ₵

9.6   12.3   37.6

6.2   6.3   10.4   11.5 |26.4   37.3

7.8   10.5   12.8   13.0

-1.1   5.9   4.9   5.0   6.9

6.9   5.9 11.7   5.8

V

R
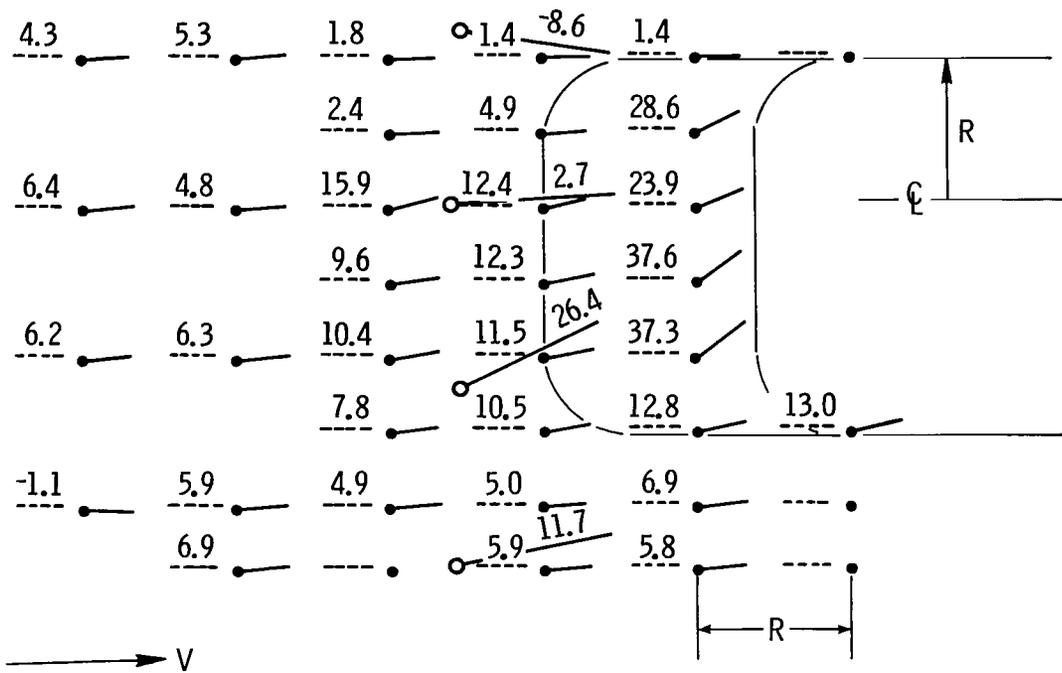
(a) $\alpha = 1.4^{\mathrm{o}}$; $C_L = 6.00$.

Figure 12.- Upflow angle, deg, between nacelles as shown by a tuft grid
located at $0.338 \frac{b}{2}$.   Flaps at $15^{\mathrm{o}}, 35^{\mathrm{o}}, 55^{\mathrm{o}}$; $C_\mu = 4.0$.

- Tufts in a chordwise plane located
  between the port nacelles

○ Tufts in vertical plane of centerline
  of outboard nacelle

17.0

25.2

16.9   17.0

19.3   21.0   31.8   29.4 $\frac{14.5}{}$ 43.3   R

25.9   35.9   44.8

19.0   20.0   32.5   37.0   57.5

30.6   32.5   32.1   30.7

25.5   25.7   28.5   28.3   28.0   23.0

31.0

V

R
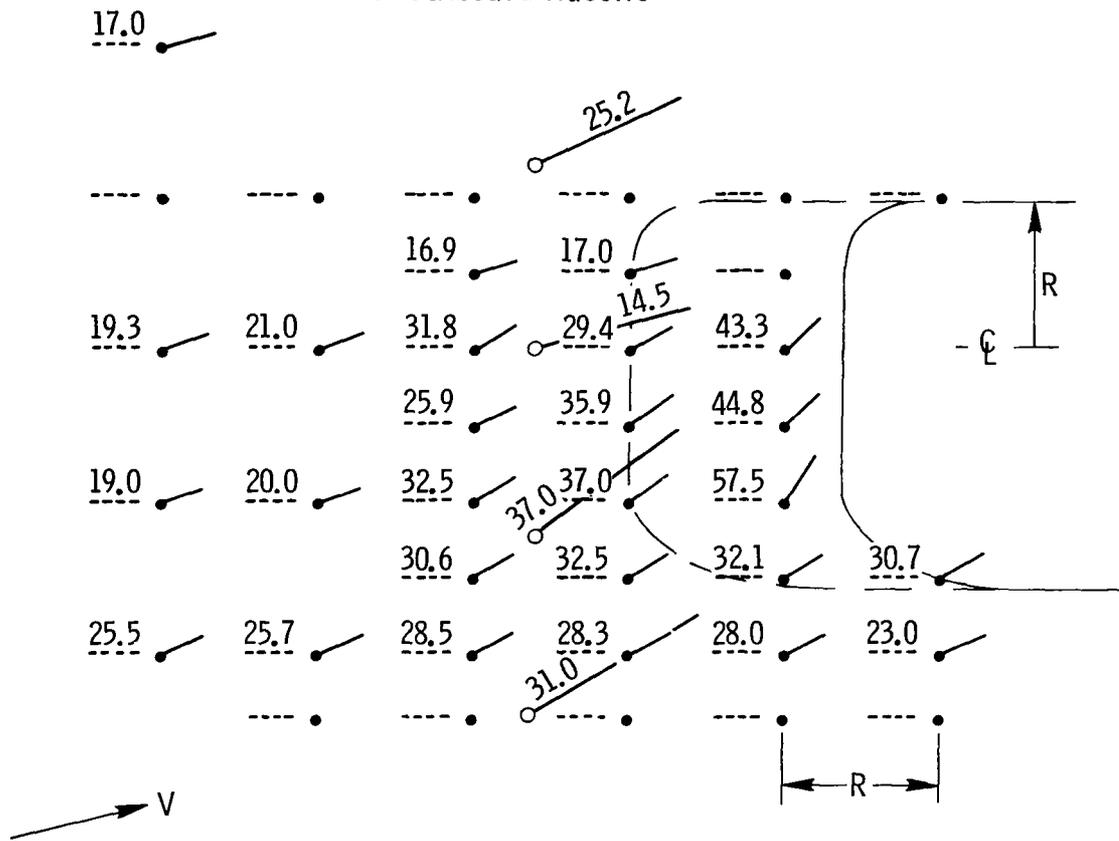
(b) $\alpha = 13.5^{\circ}$; $C_L = 8.40$.

Figure 12.- Continued.

34

- Tufts in a chordwise plane located between the port nacelles

○ Tufts in vertical plane of centerline of outboard nacelle
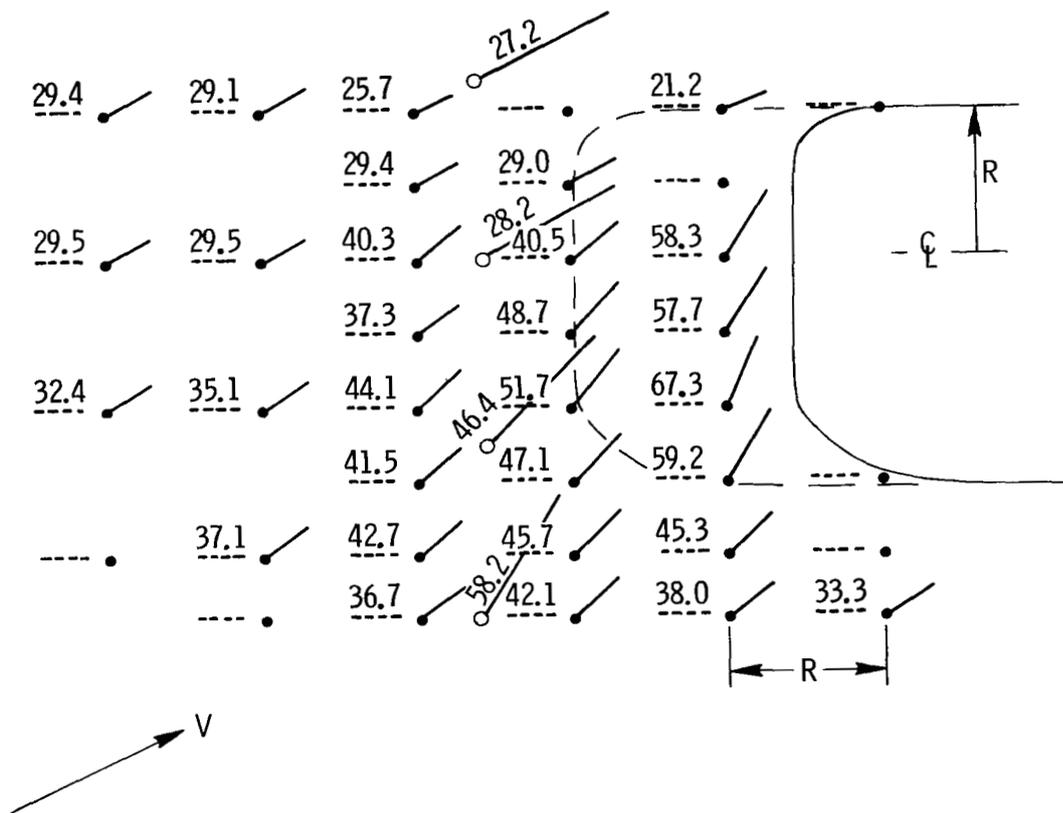
(c) $\alpha = 25.7^{O}$; $C_L = 9.33$.

Figure 12.- Concluded.

- Tufts in a chordwise plane located
  outboard of the port nacelles

0.2   1.0   4.0   2.8   1.6   1.6

1.7   1.7   5.9   4.6   3.6   3.6

                9.1   7.7   3.2   1.8   R

1.9   2.2   2.2   3.1   3.0   3.3   ₵

                0.7   2.3   6.0   4.8

1.1   -0.3   -0.3   -0.3   0.8   3.4

                -1.8   -0.3   1.2   1.9
                                             Outboard
                                             nacelle
-0.6   -0.1   -0.1   -0.1   0.7   0.8

        -3.0   -0.6   1.4   1.4   1.6

                                        |←— R —→|

——————► V
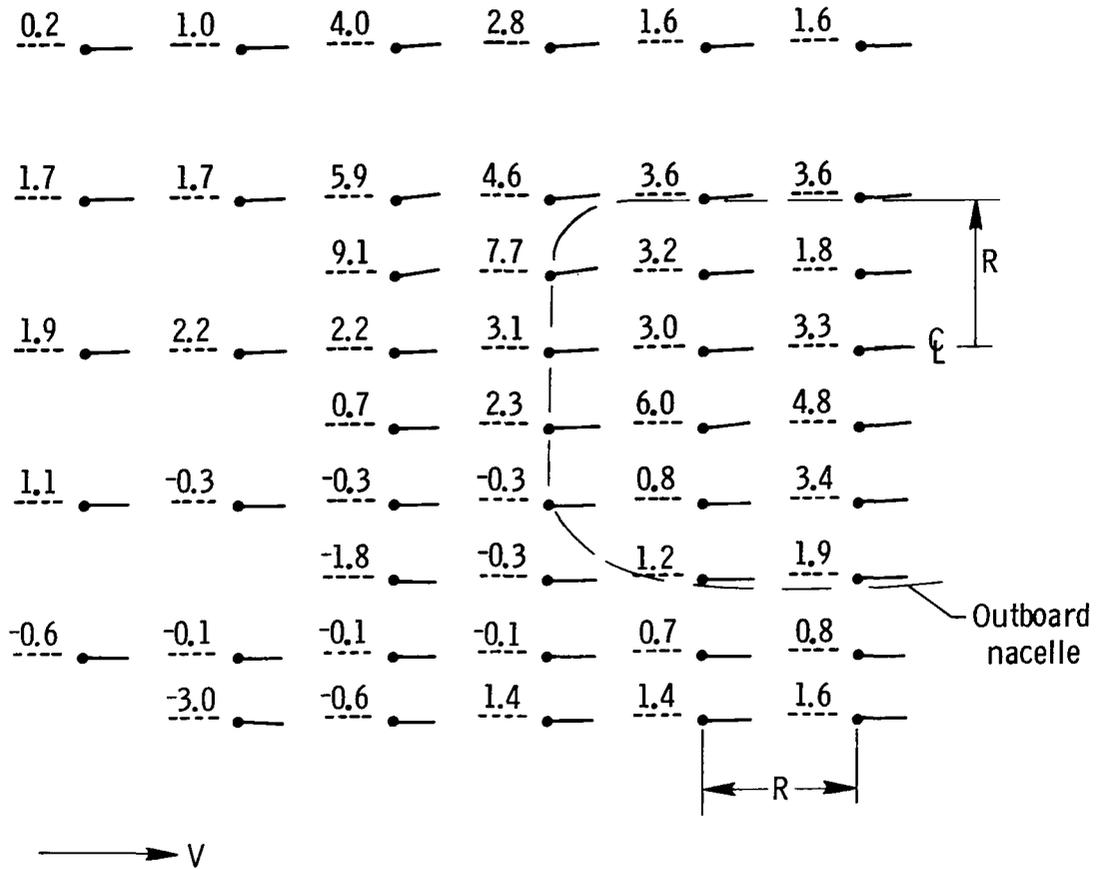
(a) $\alpha = -0.8^O$; $C_L = 2.58$.

Figure 13.- Upflow angle, deg, outboard of nacelles as shown by a tuft grid
located at $0.502\frac{b}{2}$.   Flaps at $15^O, 35^O, 55^O$; $C_\mu = 0$.

- Tufts in a chordwise plane located
  outboard of the port nacelles

9.8 — 12.4 — 13.6 — 12.5 — 13.2 — 13.2 —

13.0 — 11.6 — 16.5 — 15.9 — 14.8 — 14.6 —

19.0 — 18.0 — 10.8 — 15.1 —   R

14.4 — 14.7 — 16.3 — 14.6 — 21.1 — 23.5 — ₵

14.5 — 14.4 — 18.2 — 17.6 —

10.5 — 10.5 — 15.6 — 15.5 — 12.0 — 21.8 —

7.5 — 11.0 — 12.4 — 20.0 —

11.1 — 11.8 — 11.8 — 9.4 — 14.0 — 14.0 —   Outboard nacelle

5.0 — 5.7 — 8.6 — 9.0 — 10.6 —

|←—R—→|

→ V
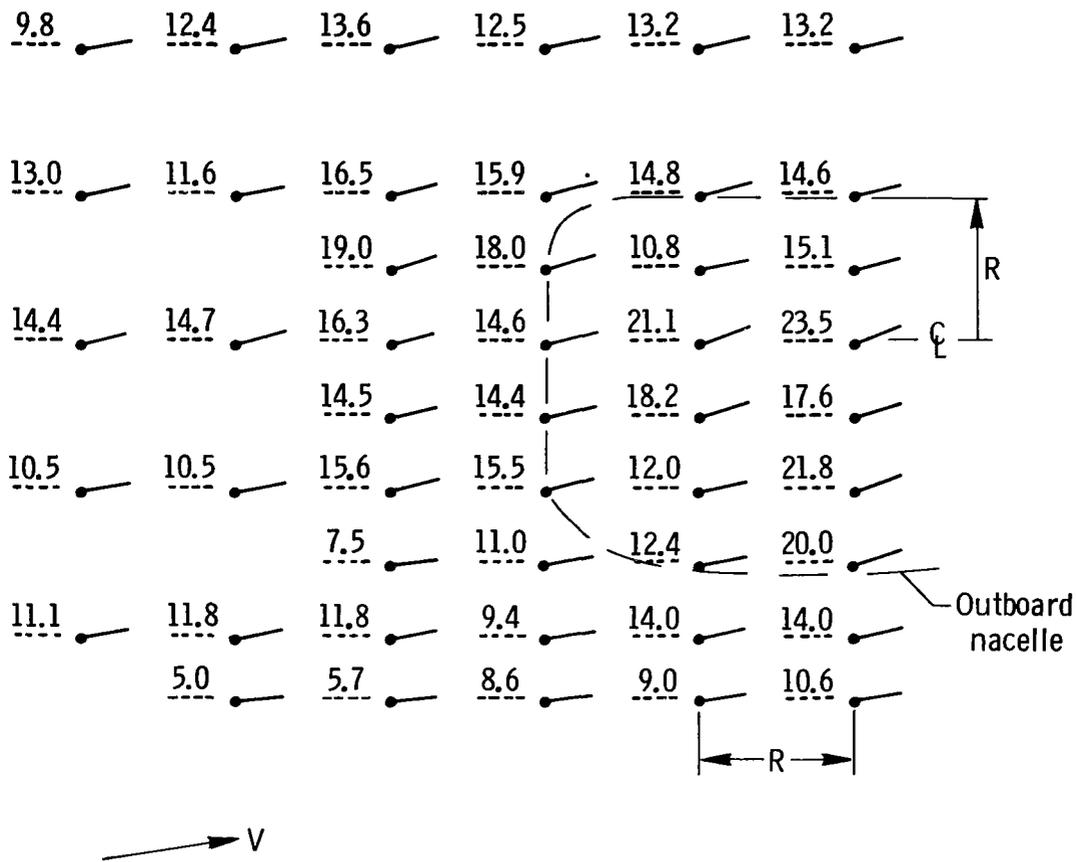
(b) $\alpha = 9.0^{\circ}$; $C_L = 3.39$.

Figure 13.- Continued.

• Tufts in a chordwise plane located
outboard of the port nacelles

21.1   22.3   25.5   24.6   22.1   21.6

24.7   22.6   26.6   21.6   20.4   22.8

                28.1   26.1   23.6   32.1   R

25.0   23.6   27.1   27.1   34.1   39.5 $\mathcal{C}_L$

                28.1   26.7   32.1   33.1

21.6   21.3   26.1   25.0   24.0   32.6

                24.0   23.9   24.1   26.1

21.3   21.7   23.1   23.4   25.1   25.8   Outboard nacelle

                17.1   16.1   19.1   19.8   20.3

V

|←—R—→|
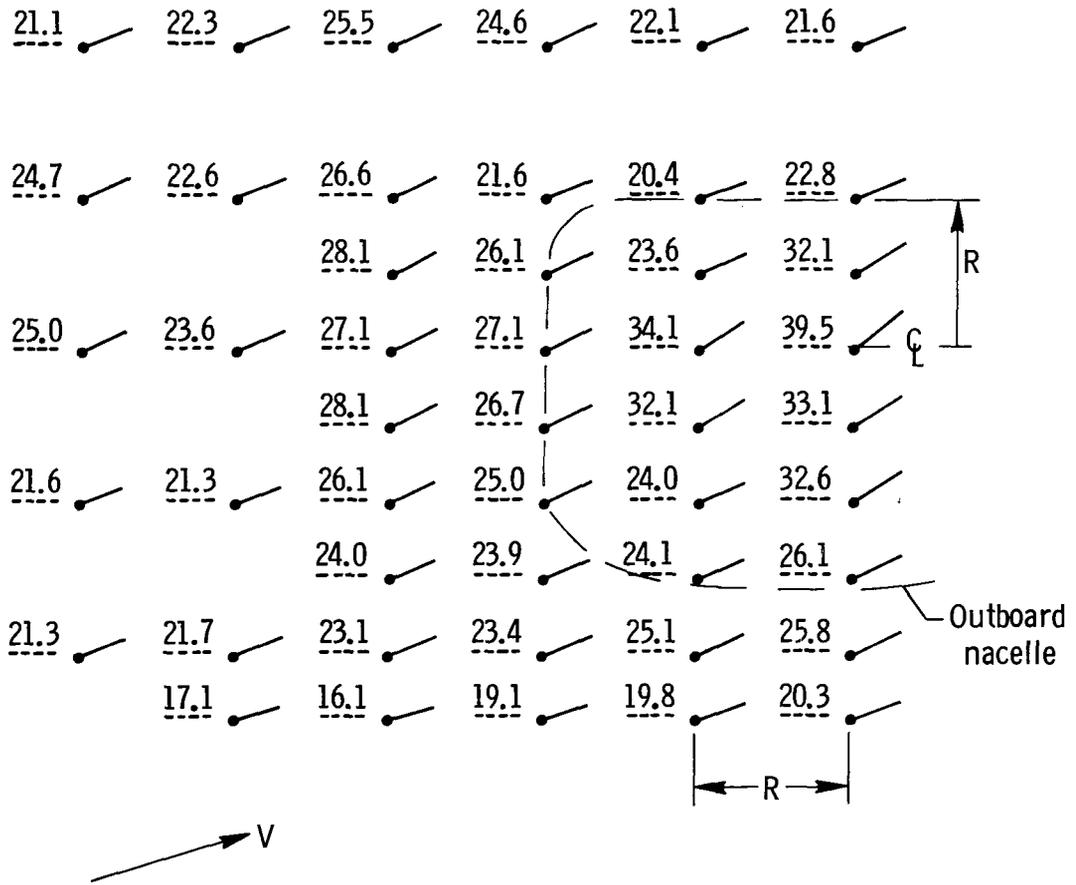
(c) $\alpha = 17.1^{O}$; $C_L = 3.80$.

Figure 13.- Concluded.

38
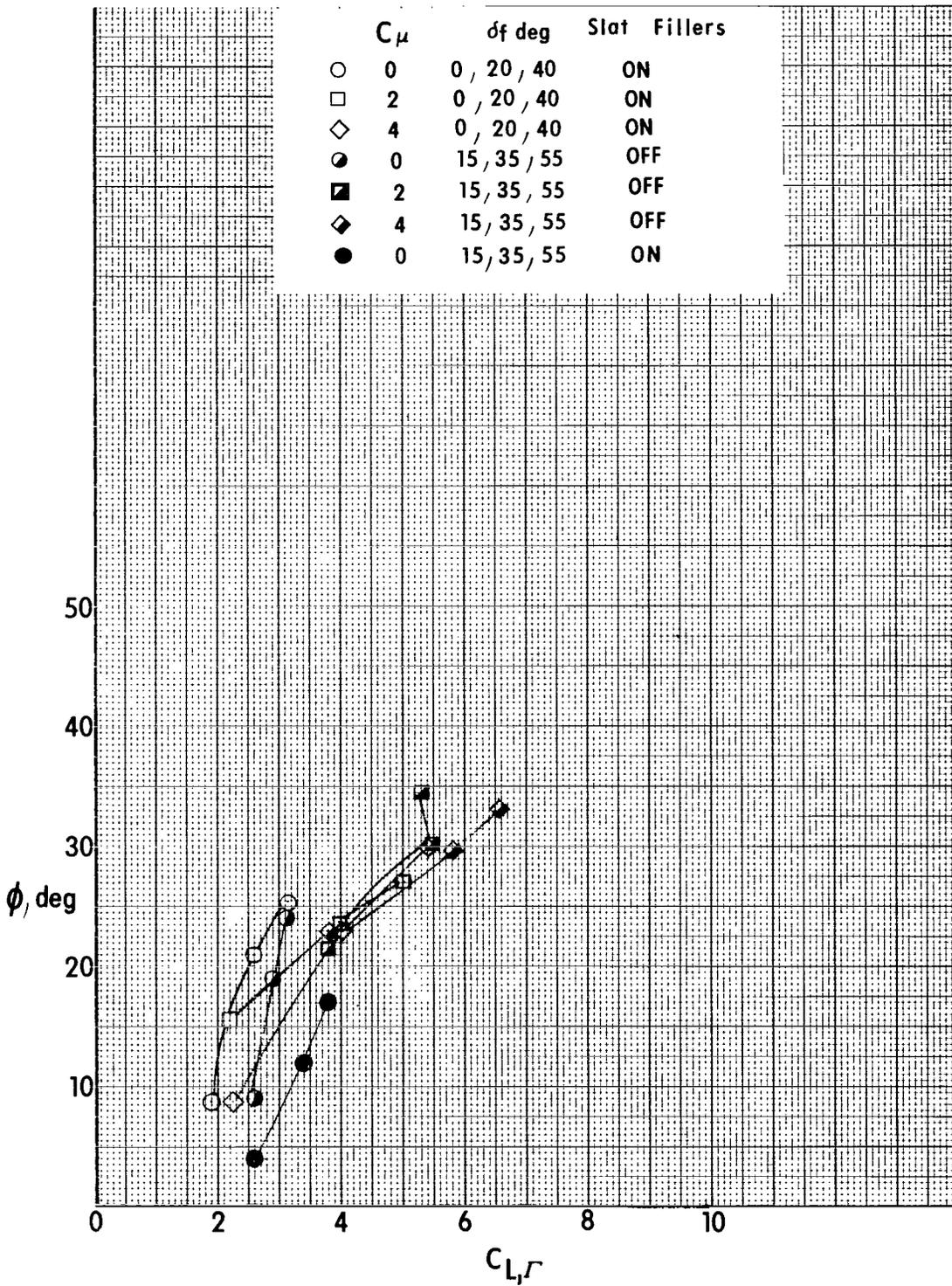
Figure 14.- Variation of upwash angle with thrust-removed lift coefficient.

50⁰ slat and 15⁰,35⁰,55⁰ flap (landing)
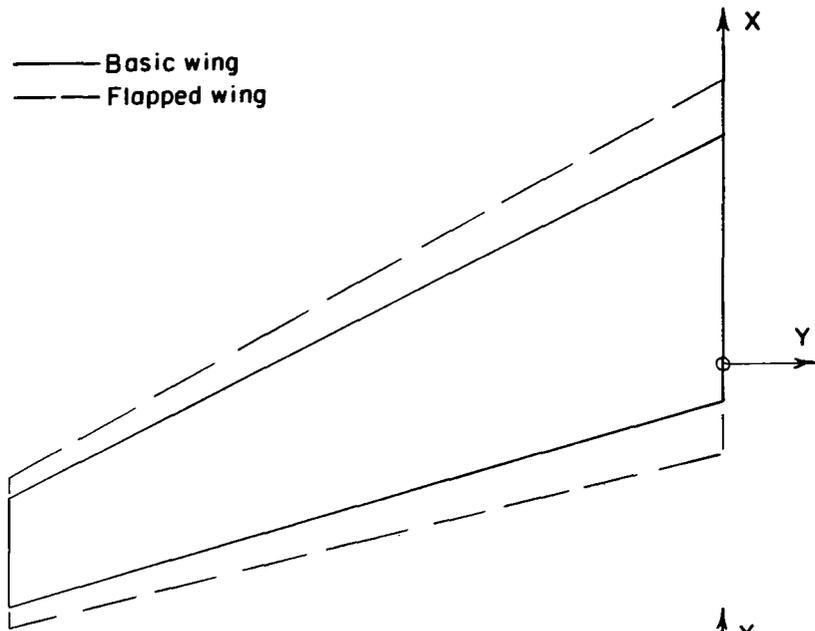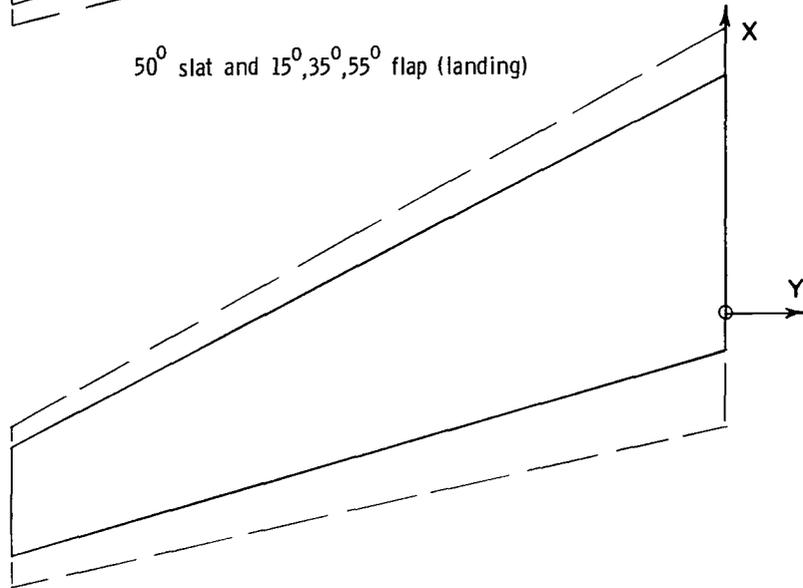
50⁰ slat and 0⁰,20⁰,40⁰ flap (take-off)

		PLANFORM DEFINITION POINTS		
Basic	x	32.57(12.82)	-17.46(- 6.88)	-32.44(-12.77)	- 4.87(- 1.92)
	y	0 (0)	-95.25(-37.50)	-95.25(-37.50)	0 (0)
Landing	x	39.01(15.36)	-14.89(- 5.86)	-35.38(-13.93)	-12.21(- 4.81)
	y	0 (0)	-95.25(-37.50)	-95.25(-37.50)	0 (0)
Take-off	x	39.01(15.36)	-14.89(- 5.86)	-36.65(-14.43)	-15.39(- 6.06)
	y	0 (0)	-95.25(-37.50)	-95.25(-37.50)	0 (0)

Figure 15.- Wing planforms used in calculations. Dimensions are in cm (in.).
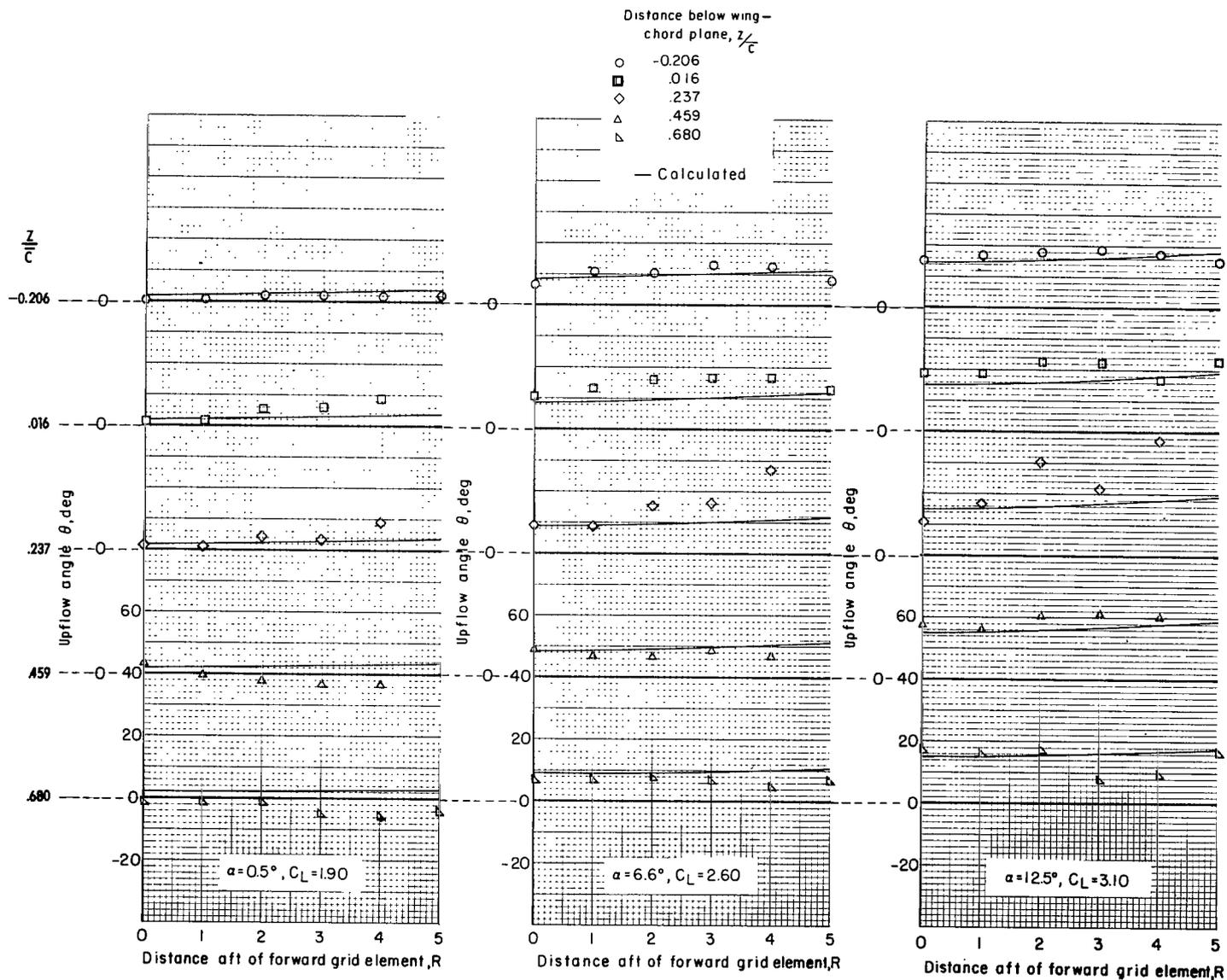
Figure 16.- Comparison of experimental and calculated flow angles; grid located between nacelles $\left(0.338\dfrac{b}{2}\right)$; flaps at $0^\circ,20^\circ,40^\circ$; $C_\mu = 0$; slat fillers on.
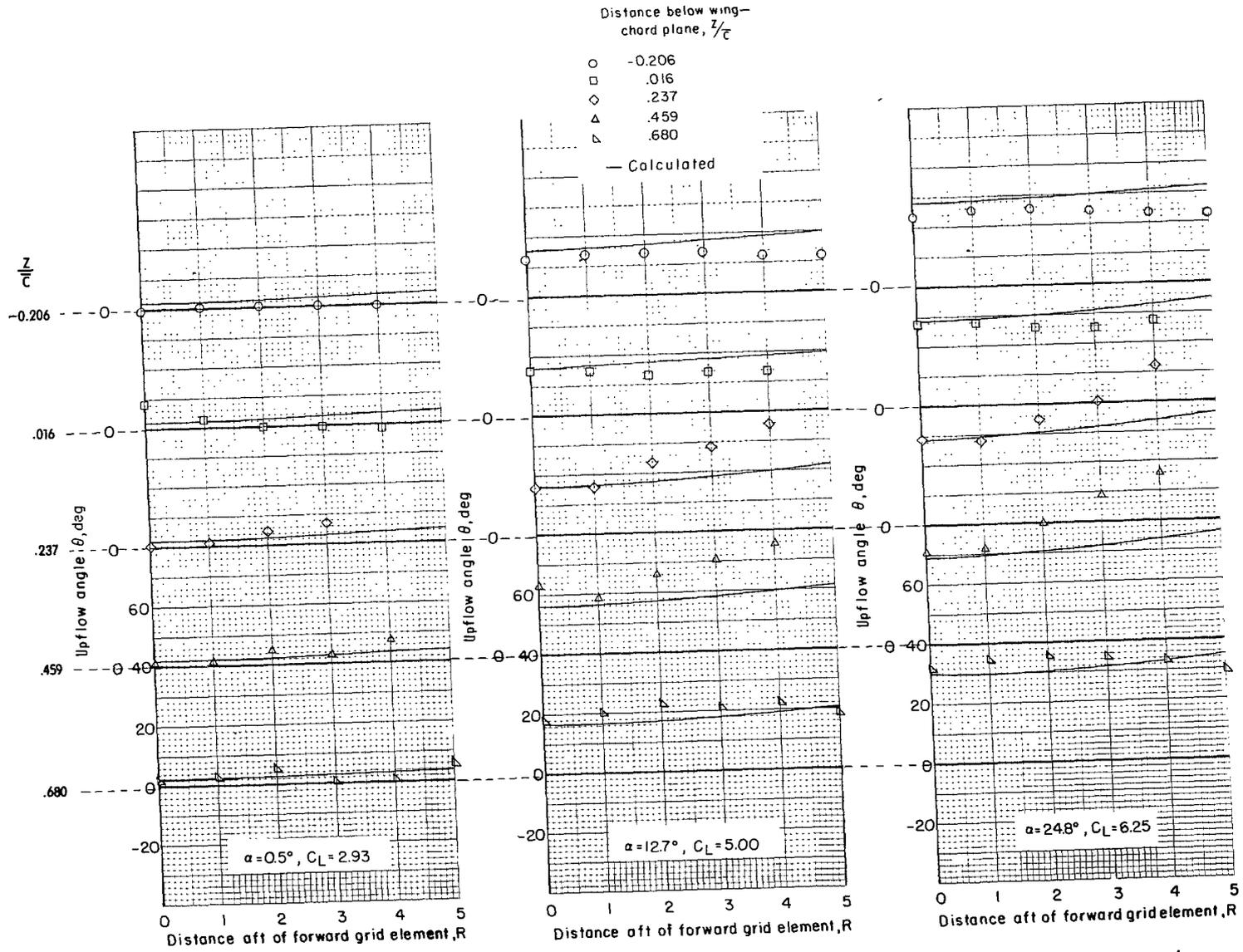
Figure 17.- Comparison of experimental and calculated flow angles; grid located between nacelles $\left(0.338\frac{b}{2}\right)$; flaps at $0°,20°,40°$; $C_\mu = 2.0$; slat fillers on.
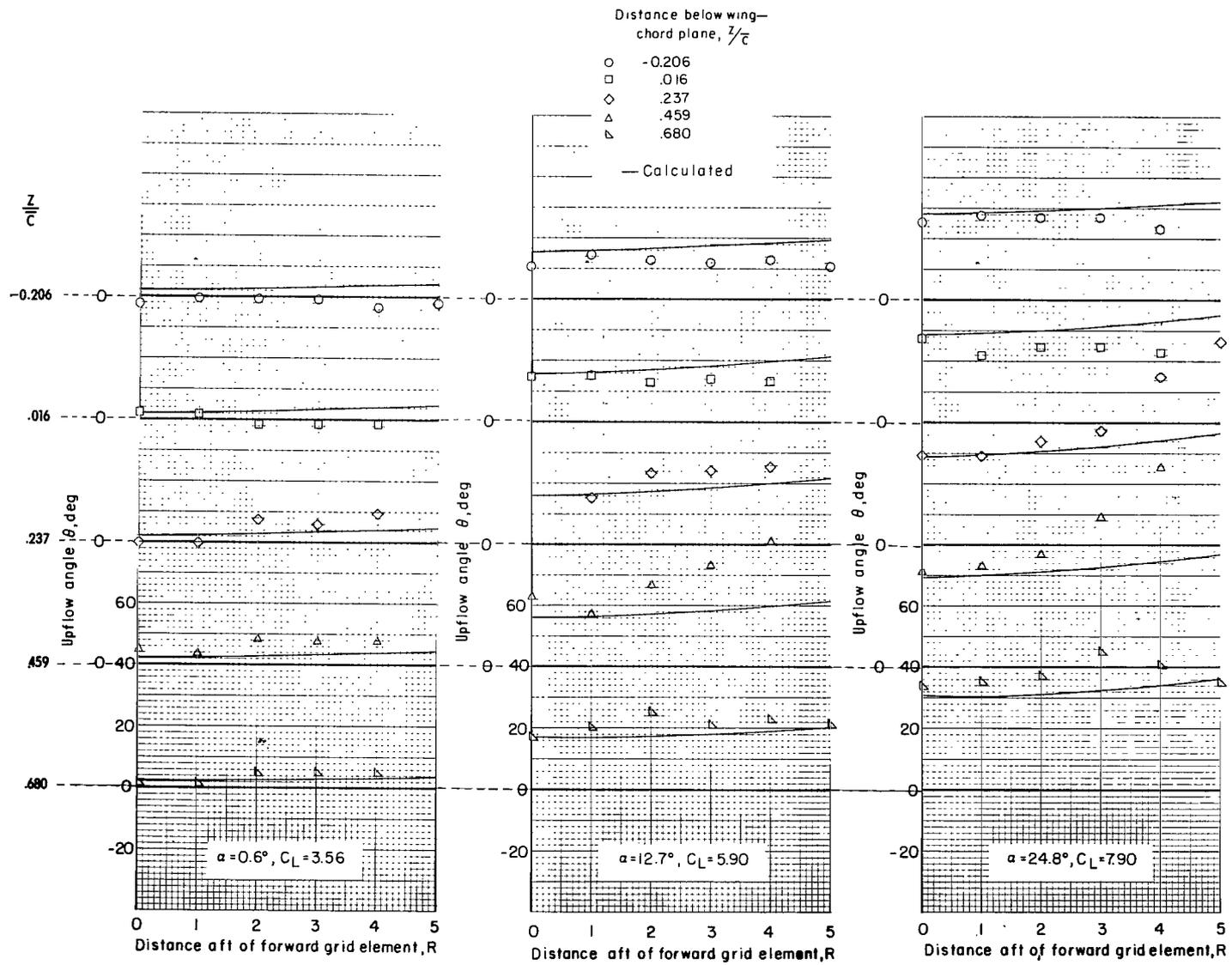
Figure 18.- Comparison of experimental and calculated flow angles; grid located between nacelles $\left(0.338\frac{b}{2}\right)$; flaps at $0^O, 20^O, 40^O$; $C_\mu = 4.0$; slat fillers on.
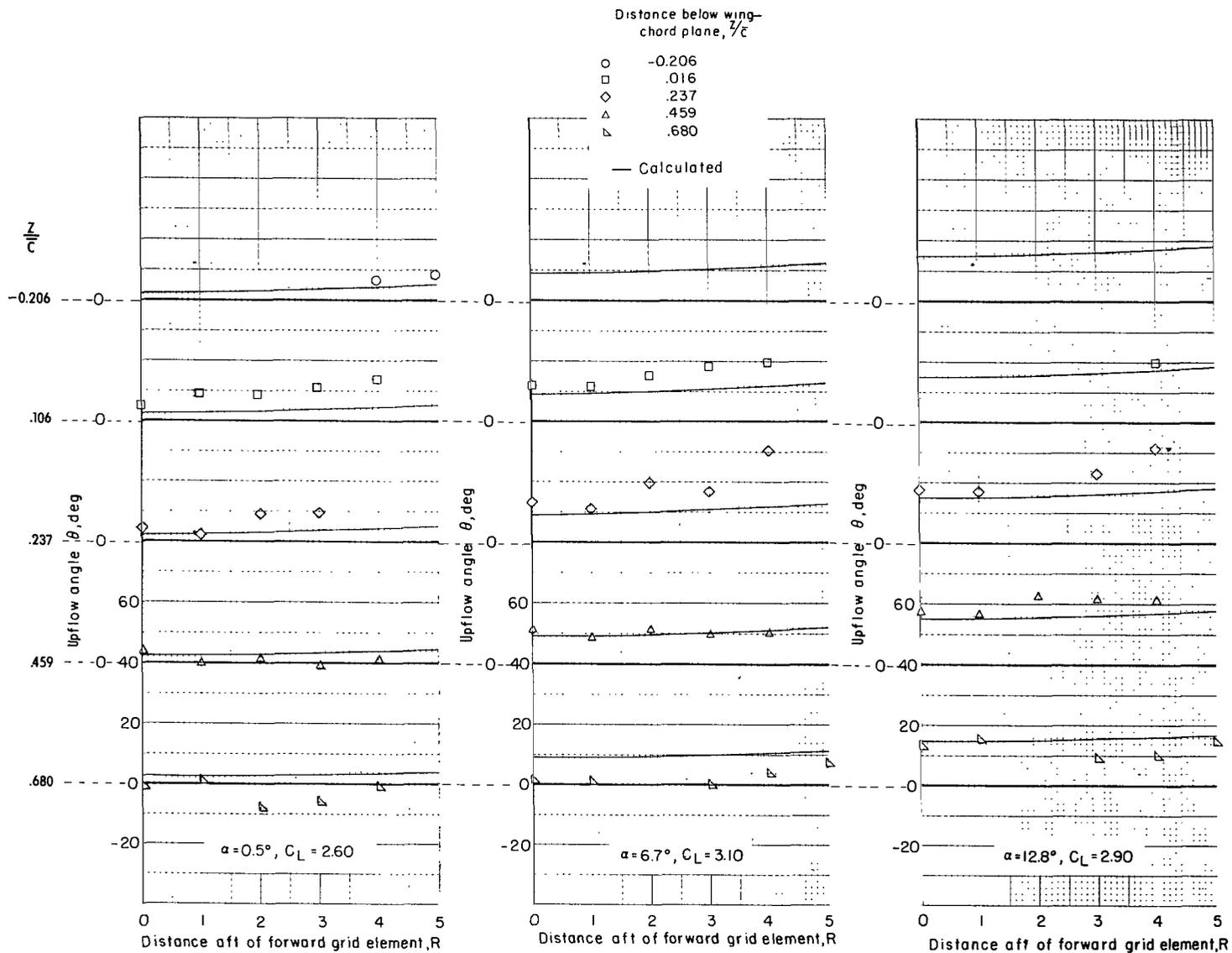
Figure 19.- Comparison of experimental and calculated flow angles; grid located between nacelles $\left(0.338\frac{b}{2}\right)$; flaps at $15^{O}, 35^{O}, 55^{O}$; $C_\mu = 0$.
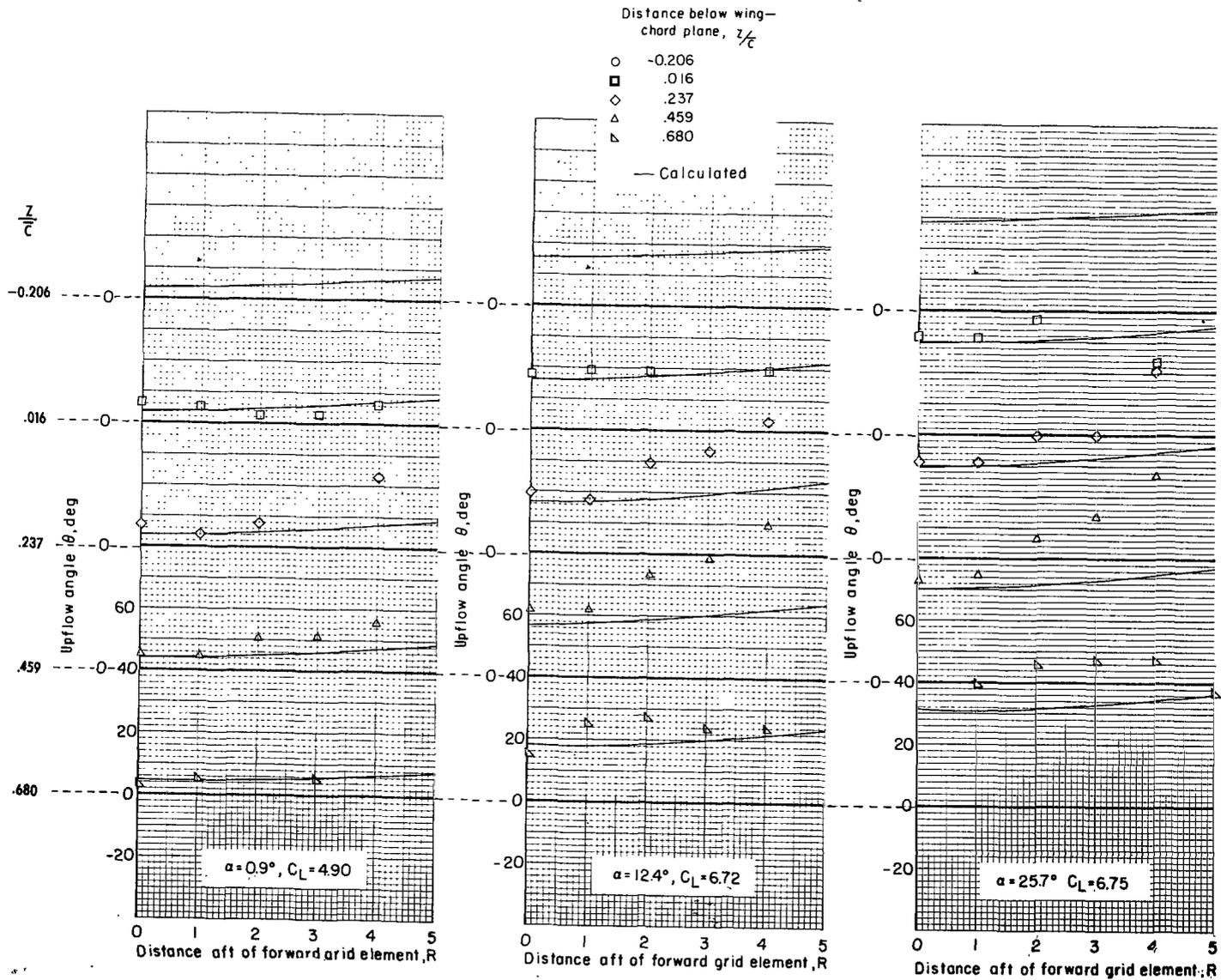
Figure 20.- Comparison of experimental and calculated flow angles; grid located between nacelles $\left(0.338\frac{b}{2}\right)$; flaps at $15^{\circ},35^{\circ},55^{\circ}$; $C_\mu = 2.0$.
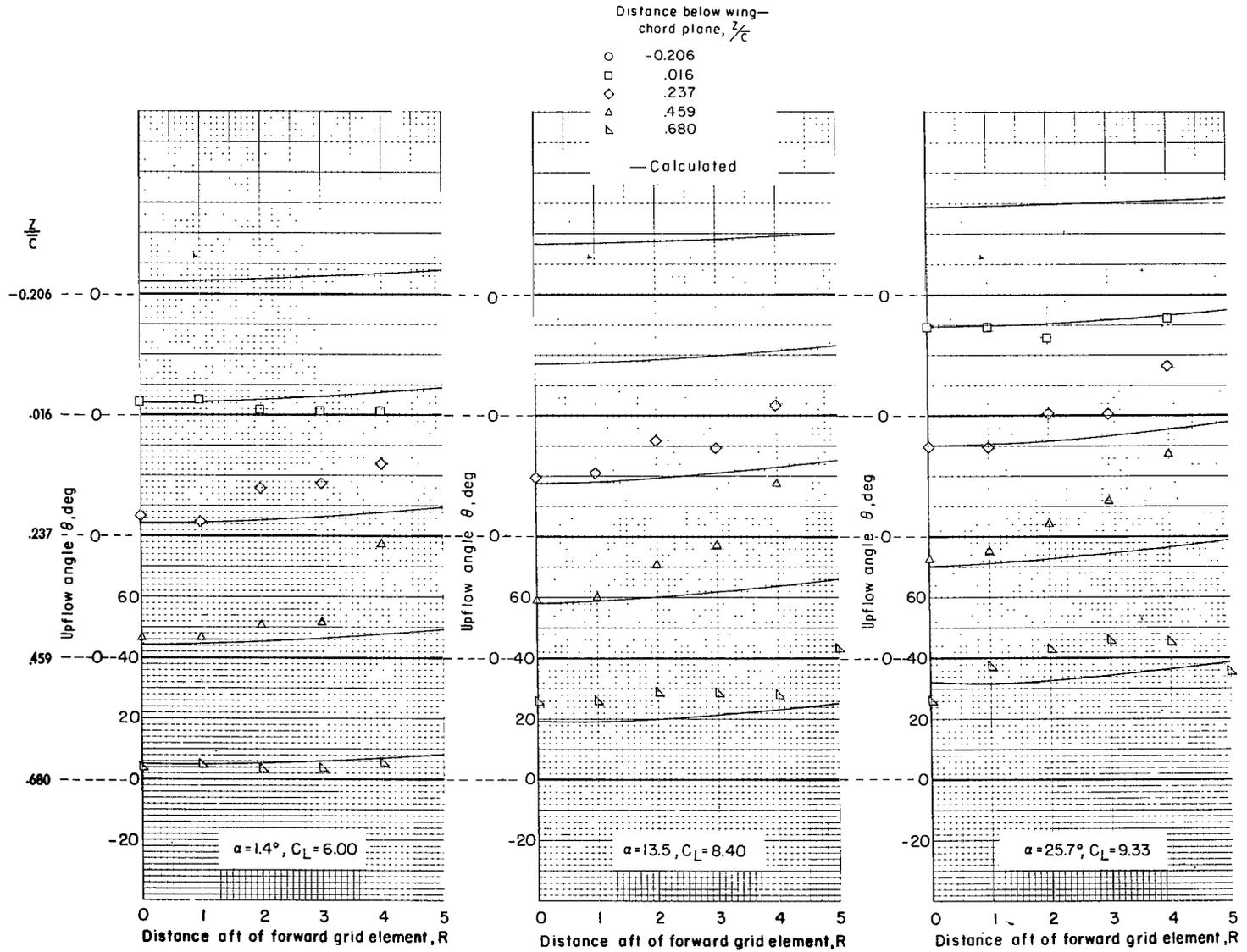
Figure 21.- Comparison of experimental and calculated flow angles; grid located between nacelles $\left(0.338\frac{b}{2}\right)$; flaps at $15^{O}, 35^{O}, 55^{O}$; $C_\mu = 4.0$.

Distance below wing—
chord plane, $z/\bar{c}$

○   -0.206
□   .016
◇   .237
△   .459
◣   .680

— Calculated

$\frac{z}{\bar{c}}$

-0.206

.016

.237

.459

.680

Upflow angle θ, deg

$a=-0.8, C_L=2.58$

Upflow angle θ, deg

$a=9.0°, C_L=3.39$

Upflow angle θ, deg

$a=17.1°, C_L=3.80$

Distance aft of forward grid element, R

Distance aft of forward grid element, R

Distance aft of forward grid element, R
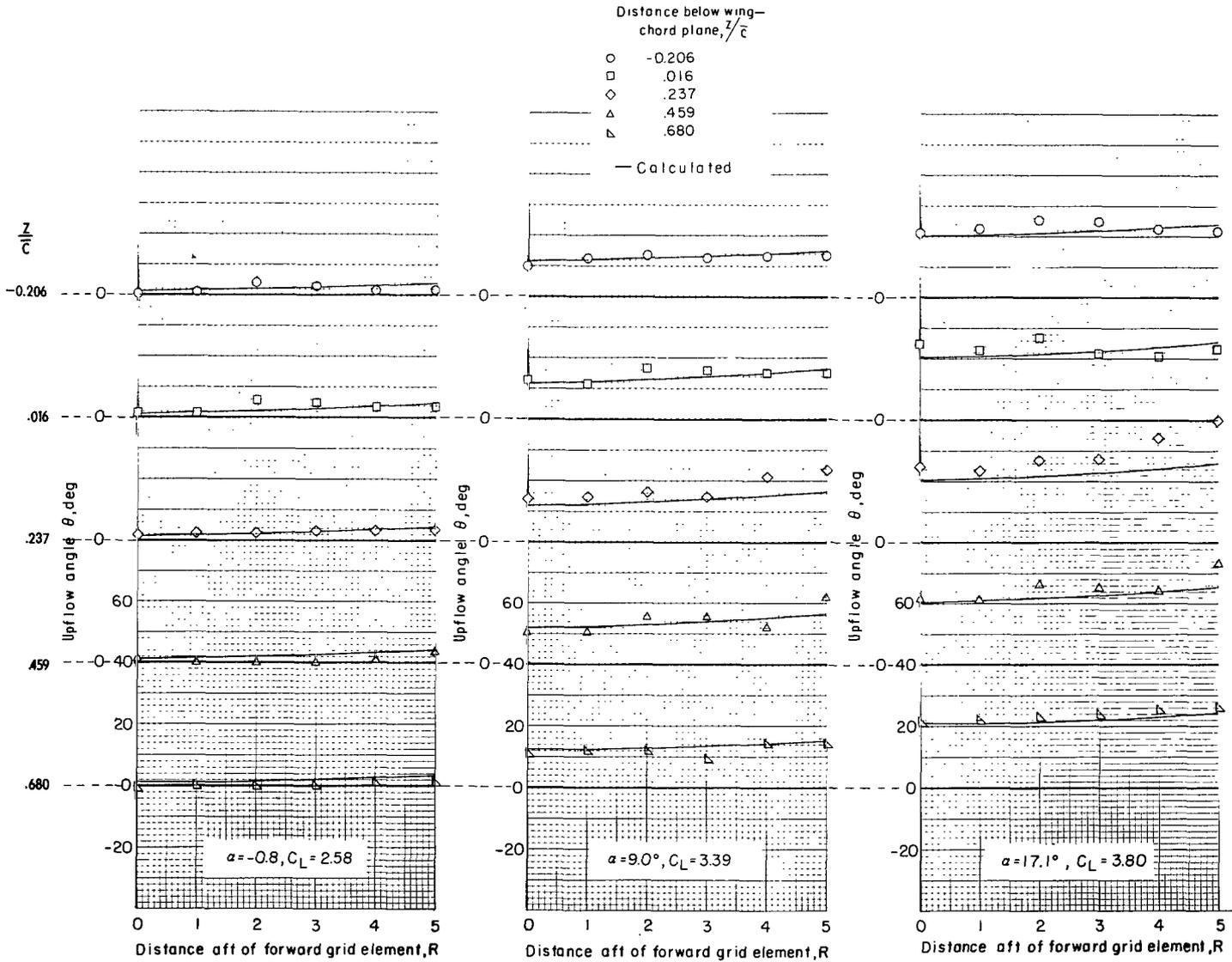
Figure 22.- Comparison of experimental and calculated flow angles; grid located at $0.502\frac{b}{2}$;
flaps at $15°, 35°, 55°$; $C\mu = 0$; slat fillers on.

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